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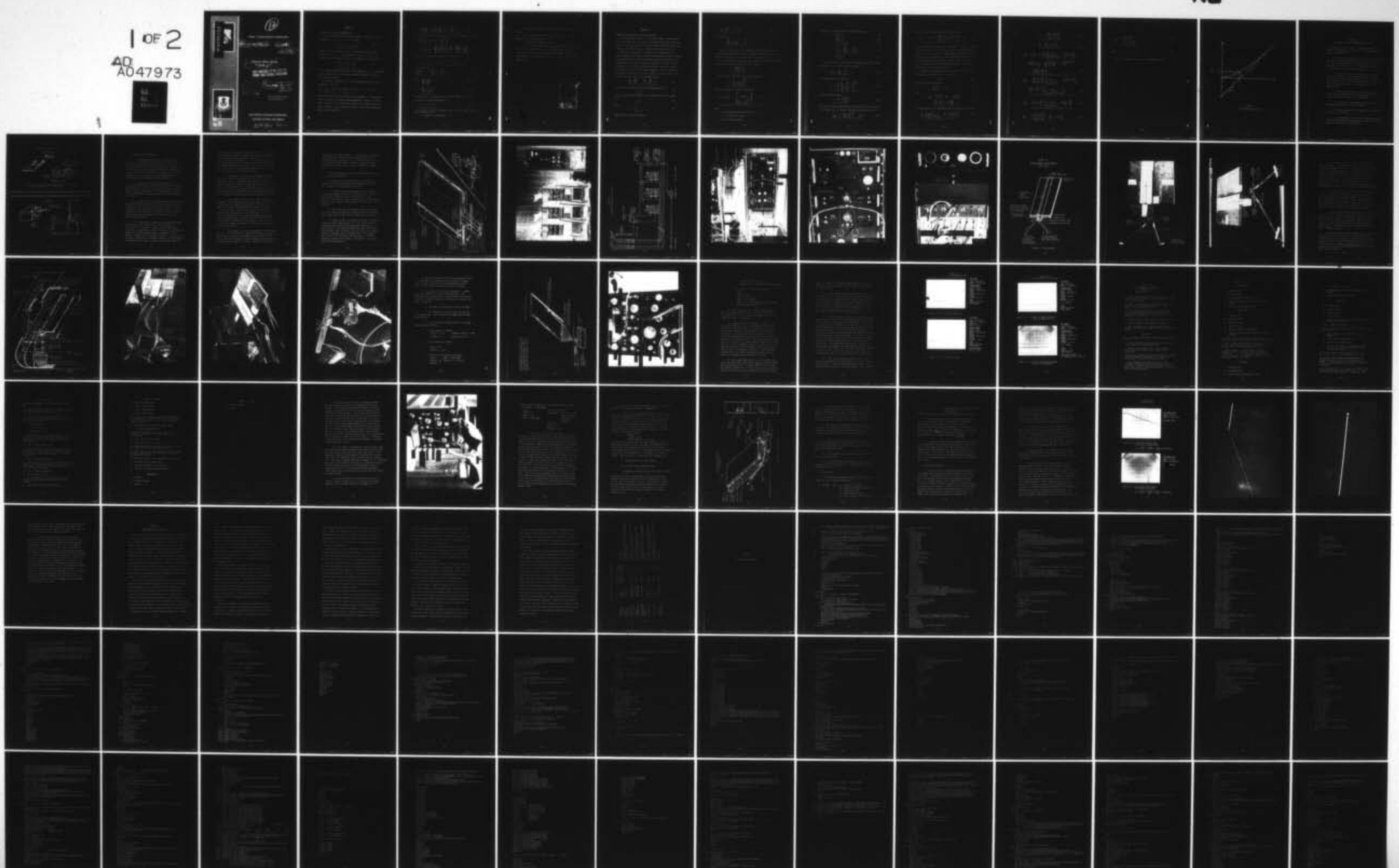

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APPENDIX A

Least Squares Fit of a Nonlinear Curve

The following discussion concerns a method for finding the values of M parameters $\lambda_1, \lambda_2, \lambda_3, \cdots \lambda_M$ in the formula

$$F = F(\lambda_1, \lambda_2, \lambda_3, \cdots \lambda_M; X) \qquad (1)$$

which render the formula a "best fit" to N measured points, having ordinates $Y_1, Y_2, Y_3, \cdots Y_N$ and abscissae $X_1, X_2, X_3, \cdots X_N$. The formula will be considered a best fit if the goodness of fit parameter

$$\Delta = \sum_{i=1}^{N} W_i \, (F_i - Y_i)^2 \qquad (2)$$

is an absolute minimum with respect to the M parameters $\{\lambda\}$. The parameters W_i are weighting factors, reflecting measurement reliability, and in this case all are unity.

The necessary criterion for Δ to be a minimum with respect to the M parameters $\{\lambda\}$ is that

$$\frac{\partial \Delta}{\partial \lambda_m} = \sum_{i=1}^{N} 2 \, W_i \, (F_i - Y_i) \left(\frac{\partial F_i}{\partial \lambda_m} \right) = 0 \quad (m = 1, 2, 3, \cdots M) \qquad (3)$$

When the formula for F is not linear in the M parameters $\{\lambda\}$, Equations(3) will not be linear in the same M unknown parameters. However, a set of linear equations can be obtained from Equations (3) by approximating each partial derivative $\frac{\partial \Delta}{\partial \lambda_m}$ by the linear terms of a Taylor series expansion about an initial point $\{\lambda_0\}$.

$$\frac{\partial\Delta}{\partial\lambda_m} = \left(\frac{\partial\Delta}{\partial\lambda_m}\right)_o + \sum_{k=1}^{M} \left(\frac{\partial^2\Delta}{\partial\lambda_m\partial\lambda_k}\right)_o \left(\lambda_k - \lambda_{ko}\right) = 0 \qquad (4)$$

The partial derivative terms in Equation (4) can be expressed as follows:

$$\left(\frac{\partial\Delta}{\partial\lambda_m}\right)_o = \sum_{i=1}^{N} 2W_i \left(F_{io} - Y_i\right) \left(\frac{\partial F_i}{\partial\lambda_m}\right)_o = C_m \qquad (5)$$

$$\left(\frac{\partial^2\Delta}{\partial\lambda_m\partial\lambda_k}\right)_o = \sum_{i=1}^{N} 2W_i\left[\left(\frac{\partial F_i}{\partial\lambda_m}\right)_o\left(\frac{\partial F_i}{\partial\lambda_k}\right)_o + \left(F_{io}-Y_i\right)\left(\frac{\partial^2 F_i}{\partial\lambda_m\partial\lambda_k}\right)_o\right] = A_{mk} \qquad (6)$$

Equations (4), (5) and (6) can now be combined to yield

$$\frac{\partial\Delta}{\partial\lambda_m} = C_m + \sum_{k=1}^{M} A_{mk} \left(\lambda_k - \lambda_{ko}\right) = 0 \quad (m = 1, 2, 3, \cdots M) \qquad (7)$$

or, in matrix form

$$\left\{\frac{\partial\Delta}{\partial\lambda}\right\} = \{C\} + \underline{A} \left\{\{\lambda\} - \{\lambda_o\}\right\} = \{o\} \qquad (8)$$

where

$$\{C\} = \left\{\left(\frac{\partial\Delta}{\partial\lambda_m}\right)_o\right\} \qquad (9)$$

$$\underline{A} = \left[\left(\frac{\partial^2\Delta}{\partial\lambda_m\partial\lambda_k}\right)_o\right] \qquad (10)$$

The column matrix of improved values of the M parameters $\{\lambda\}$ can be calculated by inverting Equation (8).

$$\{\lambda\} = \{\lambda_o\} - \underline{A}^{-1} \{C\} \qquad (11)$$

The process of fitting a nonlinear curve to a set of points consists of the following steps:

1. Estimate the M parameters $\{\lambda_o\}$.

2. Calculate the elements of $\{C\}$ and $\underline{A}$, using Equations (5) and (6).

3. Calculate the column matrix of improved values of the M parameters $\{\lambda\}$, using Equation (11).

4. Calculate Δ, using Equation (2).

5. If Δ exceeds an arbitrarily established convergence criterion, treat the latest value of $\{\lambda\}$ as $\{\lambda_o\}$ and repeat Steps 2 through 5. If Δ does not exceed the convergence criterion, then the latest values of the M parameters $\{\lambda\}$ are the ones desired for a best fit, in the least squares sense.

APPENDIX B

Mathematical Description of Flyer Plate Motion

The position-time response of a flyer plate element is characterized by a smooth curve with zero initial displacement and velocity, approaching terminal velocity at late time. The rate at which the position-time curve approaches the terminal velocity asymptote varies from shot to shot.

Inspection of the graph of a hyperbola in any standard text on analytic geometry shows that an ordinary (second order) hyperbola satisfies the conditions of zero initial displacement (with an upward shift of the origin), zero initial slope and terminal asymptote. All that is needed in addition is to introduce a parameter which will control the rate at which the curve approaches the terminal asymptote. This is accomplished by letting the exponent be a variable parameter, so that the basic form of the equation for an n^{th} order hyperbola becomes

$$\left(\frac{y - y_o}{b}\right)^n - \left(\frac{t - t_o}{h}\right)^n = 1 \tag{1}$$

To satisfy the condition of zero initial displacement, set

$$y_o = - b \tag{2}$$

and for mathematical convenience in the derivations to follow, assume that

$$t_o = 0 \tag{3}$$

and set

$$\frac{1}{h} = a \tag{4}$$

Equation (B-1) then takes the form

$$\left(\frac{y}{b} + 1\right)^n = 1 + (at)^n \tag{5}$$

or, solving for y,

$$y = b\left\{\left[1 + (at)^n\right]^{\frac{1}{n}} - 1\right\} \tag{6}$$

Figure B-1 illustrates how the parameters of an n^{th} order hyperbola can be determined graphically using the terminal asymptote. The terminal asymptote intersects the T axis at $t = \frac{1}{a} = h$, and intersects the Y axis at $y = -b$. The ordinate to the curve at the point where the terminal asymptote intersects the T axis is $y = V = (2^{\frac{1}{n}} - 1)b$, so that

$$n = \frac{\log 2}{\log\left(\frac{V}{b} + 1\right)} \tag{7}$$

The velocity at any time is given by the equation

$$\dot{y} = ab \left[\frac{(at)^n}{1 + (at)^n}\right]^{\frac{n-1}{n}} \tag{8}$$

and the acceleration is given by the equation

$$\ddot{y} = a^2 b\ (n-1) \left\{\frac{(at)^{n-2}}{\left[1 + (at)^n\right]^{\frac{2n-1}{n}}}\right\} = \frac{p}{\rho H} \tag{9}$$

where

p = instantaneous detonation pressure

ρ = flyer plate mass density

H = flyer plate thickness

Inspection of Equations (6), (8), and (9) shows that

$$\underline{\underline{y\ (0) = 0}} \tag{10}$$

$$\underline{\underline{\dot{y}\ (0) = 0}} \tag{11}$$

$$\underline{\underline{\dot{y}\ (\infty) = ab = \frac{b}{h}}} \tag{12}$$

$$\underline{\underline{\ddot{y}\ (0) = \begin{cases} 0 & (n>2) \\ a^2 b & (n=2) \\ \infty & (n<2) \end{cases}}} \tag{13}$$

$$\underline{\underline{\ddot{y}\ (\infty) = 0}} \tag{14}$$

The time at which the flyer plate displacement equals the standoff distance, s, is the time of impact, t_i, where

$$\underline{\underline{(at_i)^n = \left(\frac{s}{b} + 1\right)^n - 1}} \tag{15}$$

The impact velocity is therefore

$$\underline{\underline{V_P = ab \left[\frac{\left(\frac{s}{b} + 1\right)^n - 1}{\left(\frac{s}{b} + 1\right)^n} \right]^{\frac{n-1}{n}}}} \tag{16}$$

and the collision angle is

$$\underline{\underline{\alpha = \tan^{-1} \left(\frac{V_P}{V_D}\right)}} \tag{17}$$

Note that this entire analysis assumes the motion of the flyer plate to be purely vertical. When n>2 the peak acceleration occurs at

$$\underline{\underline{t_{PEAK} = h \left(\frac{n-2}{n+1}\right)^{\frac{1}{n}} \quad (n>2)}} \tag{18}$$

and the peak acceleration is given by the expression

$$\ddot{y}_{PEAK} = a^2 b\ (n-1) \left[\frac{(n+1)^{n+1} \quad (n-2)^{n-2}}{(2n-1)^{\ 2n-1}} \right]^{\frac{1}{n}} \qquad (n>2) \qquad (19)$$

Because the theoretical acceleration is infinite at t=0 for n<2, Equations (18) and (19) cannot be used to calculate rise time and peak detonation pressure for all conditions. Had a double exponential explosive pressure pulse been assumed, e.g. [JACOBSEN AND AYRE (1958, 152, Fig P 3-11)] this particular problem would have been avoided. This type of curve is employed at the Air Force Weapons Laboratory to describe an electromagnetic pulse (EMP) time history.

In obtaining the parametric derivatives needed for least squares curve fitting, use was made of the fact that if

$$Y = U^V \qquad (20)$$

which can be written in the form

$$Y = \left(e^{\ln U}\right)^V = e^{V \ln U}$$

then

$$\frac{dY}{dX} = e^{V \ln U} \left(\frac{V}{U} \frac{dU}{dX} + \ln U \frac{dV}{dX} \right)$$

$$= Y \left(\frac{V}{U} \frac{dU}{dX} + \ln U \frac{dV}{dX} \right) \qquad (21)$$

The equations for the required partial derivatives are as follows:

$$\frac{\partial y}{\partial n} = \left\{ \frac{\ln(at)}{n\left[1 + (at)^{-n}\right]} - \frac{\ln\left[1 + (at)^n\right]}{n^2} \right\} \qquad (22)$$

$$\frac{\partial y}{\partial a} = \frac{b\left[1 + (at)^n\right]^{\frac{1}{n}}}{a\left[1 + (at)^{-n}\right]} \tag{23}$$

$$\frac{\partial y}{\partial b} = \left[1 + (at)^n\right]^{\frac{1}{n}} - 1 \tag{24}$$

$$\begin{aligned}\frac{\partial^2 y}{\partial n^2} = b\left[1 + (at)^n\right]^{\frac{1}{n}} \Bigg[& \left\{\frac{\ln(at)}{n\left[1+(at)^{-n}\right]} - \frac{\ln\left[1+(at)^n\right]}{n^2}\right\}^2 \\ & - \frac{\ln(at)}{n^2\left[1+(at)^{-n}\right]} + \frac{(at)^{-n}\ln^2(at)}{n\left[1+(at)^{-n}\right]^2} + \frac{2\ln\left[1+(at)^n\right]}{n^3} \\ & - \frac{(at)^n \ln(at)}{n^2\left[1+(at)^n\right]}\Bigg]\end{aligned} \tag{25}$$

$$\begin{aligned}\frac{\partial^2 y}{\partial n \partial a} = & \frac{b\left[1+(at)^n\right]^{\frac{1}{n}}}{a\left[1+(at)^{-n}\right]}\left\{\frac{\ln(at)}{n\left[1+(at)^{-n}\right]} - \frac{\ln\left[1+(at)^n\right]}{n^2}\right\} \\ & + b\left[1+(at)^n\right]^{\frac{1}{n}}\left\{\frac{\ln(at)}{a\left[1+(at)^{-n}\right]^2 (at)^n}\right\}\end{aligned} \tag{26}$$

$$\frac{\partial^2 y}{\partial n \partial b} = \left[1+(at)^n\right]^{\frac{1}{n}}\left\{\frac{\ln(at)}{n\left[1+(at)^{-n}\right]} - \frac{\ln\left[1+(at)^n\right]}{n^2}\right\} \tag{27}$$

$$\frac{\partial^2 y}{\partial a^2} = \frac{b\left[1+(at)^n\right]^{\frac{1}{n}}}{a^2\left[1+(at)^{-n}\right]^2}\left[1 + n\,(at)^{-n}\right] \tag{28}$$

$$\frac{\partial^2 y}{\partial a \partial b} = \frac{\left[1+(at)^n\right]^{\frac{1}{n}}}{a\left[1+(at)^{-n}\right]} \tag{29}$$

$$\frac{\partial^2 y}{\partial b^2} = 0 \tag{30}$$

Since y is a continuous function, cross derivatives are equal.

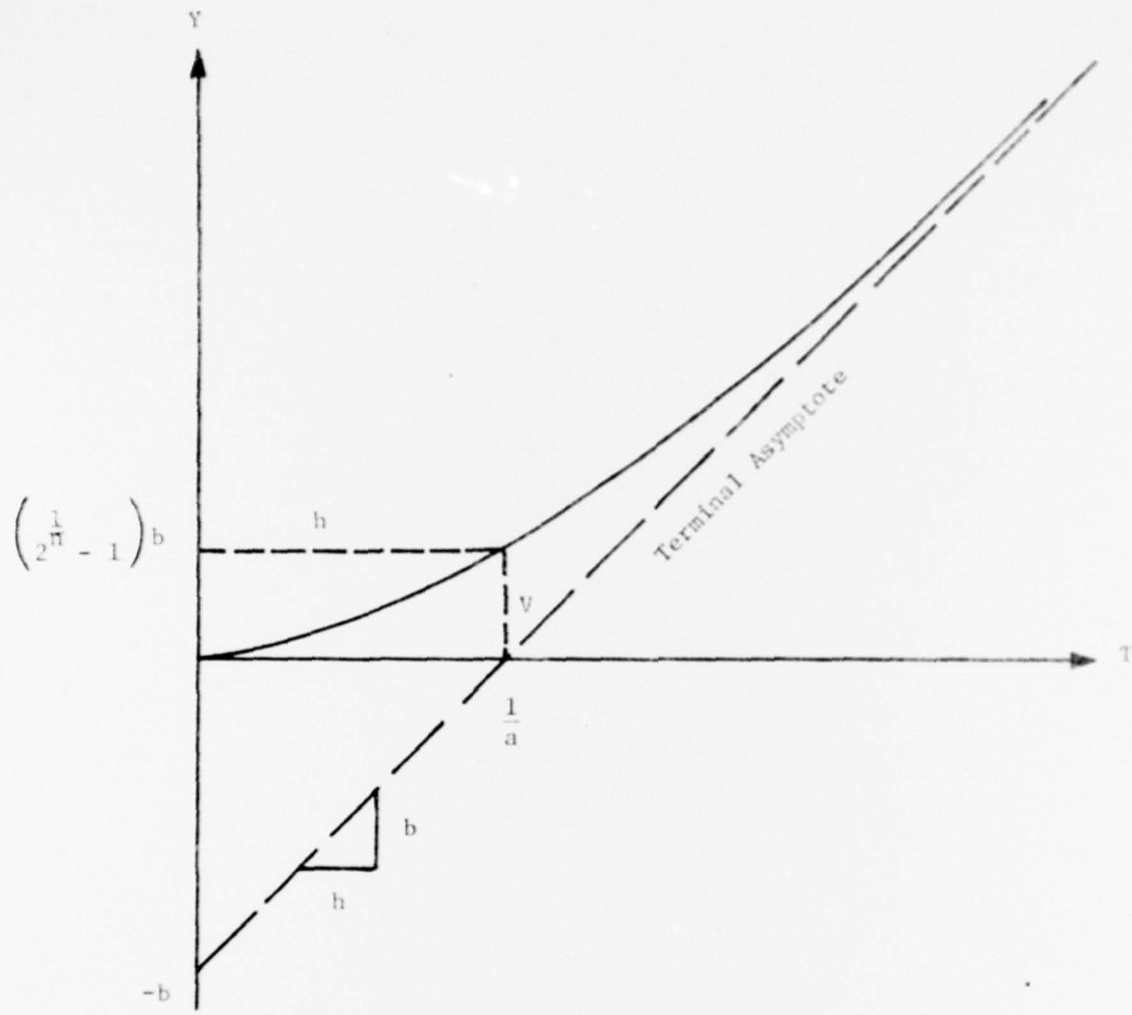


FIGURE B-1

Nth ORDER HYPERBOLIC CURVE

APPENDIX C

USAFA EIW TEST SITE INSTRUMENTATION SYSTEM

The following section constitutes a complete description of the electronic instrumentation system used at the USAFA Explosive Impulse Welding Research Site.

A. The EIW Research conducted at this facility required the measurement of various data including, but not necessarily limited to, explosive detonation pressure, interface plate collision pressure, detonation velocity, and a flash radiograph of the colliding plates. Several unique problems had to be resolved:

1. All the data for each test must be acquired during the time of burning of a slow detonation velocity explosive with detonation velocity in the range V_d = 2500 m/s - 4000 m/s. This represents a total time of between about 90 - 138 μsec, assuming a 12" long specimen and 16 μsec burning time for the line wave generator.

2. Triggering circuits must be designed so that all of the measurement equipment will be reliably triggered at the instant the blasting cap initiates the detonation.

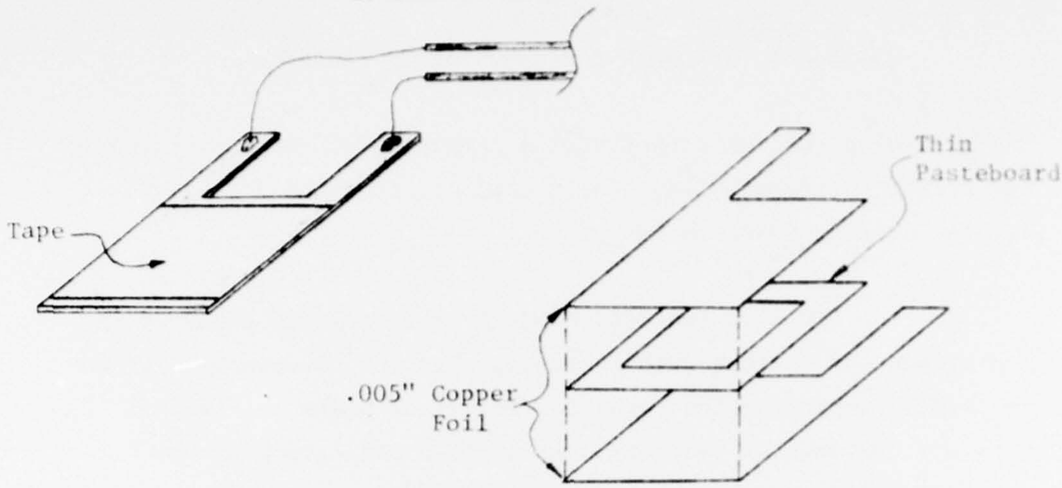
3. The proper time relationships between the various measuring devices must be accurately maintained.

4. The data obtained must be permanently and accurately recorded for later analysis.

5. The radiographic film cassette and mounting terminal strip for the wiring to the specimen must be protected from the effects of the blast and shock generated.

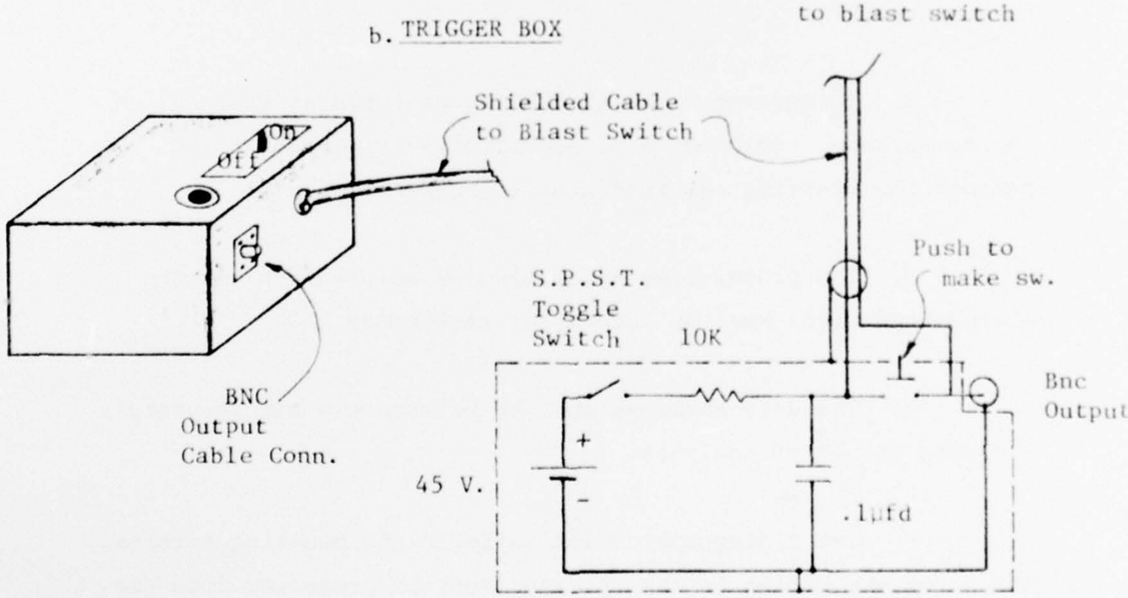
FIGURE C-1 TRIGGER DETAILS

a. BLAST SWITCH



NOTE: Blast switch assembled with two-sided tape and secured with a strip of single-sided, cloth-backed tape.

b. TRIGGER BOX



B. Solutions to the Problems

1. The triggering circuits were a two-part problem. The first was a method suitable for utilizing a "make" type of switch to trigger the electronics at time T = 0. The second was generating a pulse of the proper amplitude and length to cause reliable triggering of the equipment. The Flash X-Ray system used in conjunction with the stress measurement system required a triggering pulse of a certain amplitude and duration and this pulse was also used to trigger the other electronics.

2. A "make" type of switch was constructed from .010 thick copper foil and thin pasteboard, and placed directly beneath the blasting cap. Details of this switch are shown in Figure C-1. When the cap fired, the upper foil was forced through the hole in the pasteboard and contacted the lower foil, thereby completing the circuit.

3. A "trigger" box was constructed to provide the necessary pulse output, and was connected to the "make" switch, (hereafter referred to as the "blast" switch) by means of #18 AWG 2-conductor shielded wire. Details of the trigger box are shown in Figure C-1. A pushbutton switch on this box, essentially in parallel with the blast switch was used to trigger the electronics for set-up, prior to the actual shot.

4. The output of the trigger box was transmitted through RG58/U coaxial cable, connecting the box to the inputs of Oscilloscope #1, (Time base #1 trigger input), Oscilloscope #3 (Time base #1 trigger input), Flash X-Ray Time Delay Input Amplifier, Channel #1 of the Pulsar Power Supply, and Channel #1 of the Abtronics Time Delay Pulse Generator. (Channel #2 of this unit is not used). Additionally, the output of channel #1 of the Abtronics was connected to the input of Channel #2 of the Power Supply and

to the time base #1 trigger input of Oscilloscope #2. Since Scope #2 and Channel #2 of the Power Supply were used for the interface pressure measurement, the appropriate time delay from time T = 0 could be dialed into the Abtronics. It was necessary to delay the Power Supply output for this measurement because the pulse output has a maximum length of about 100 μsec, and the interface pressure pulse could arrive at the gage anywhere from about 80 μsec to over 100 μsec, depending on the detonation velocity.

5. Oscilloscope #1 was used for the detonation pressure measurement. The power supply pulse was observed on the bottom trace (using time base "A") and the magnified pressure pulse (superimposed on top of the power supply pulse) was observed on the top trace (using time base "B"). A type "D"; "L"; "A"; "CA", "53/54", or similar type of preamplifier plug-in could be used for the bottom trace, and a type "W" or "Z" could be used for the top trace. The "W" type of preamp was found to be entirely satisfactory.

6. Oscilloscope #2 was used for the interface pressure measurement. The configuration here was the same as for Oscilloscope #1, except that the input triggering pulse was delayed by the amount of time dialed into the time-delay generator (from time T = 0). Additionally, the top trace of Scope #1 always needed some time delay (with respect to the bottom trace, or T = 0), because of the difference in the horizontal magnification factor. It also sometimes proved convenient to add some delay to the top trace of Scope #2 depending on several factors. These factors, as well as the complete operation of the Oscilloscope and circuits will be described later.

7. Oscilloscope #3 was used for measurement of the Detonation Velocity. It was connected to a specially constructed Detonation Velocity probe (glued to the specimen) by means of RG58/U cable and to a specially constructed constant current source that provided a constant current output for the probe. Details of this circuit

configuration are shown in Figure C-2. For additional information on the Flash X-Ray System concerning troubleshooting, repair calibration, etc., consult the Instruction Manual Model 730/2650 (Fexitron Pulsed X-Ray Systems), readily available from Field Emission Corp., Melrose Ave. at Linke St., McMinnville, Oregon, 97128.

C. Setup, Calibration, and Operation of the Complete System for a Fully Instrumented Test.

1. Open both bottles of gas and adjust system Freon chamber pressure for about 19 PSI, system tubehead pressure for 18 - 20 ounces; and nitrogen pressure for 25 PSI.

2. Activate X-Ray Console main power switch, and make certain High Voltage key switch is in "OFF" position. Ascertain that "power on" lamps are lighted for Abtronics time delay generator, Pulsar Power On supply, and X-Ray Delay Trigger amplifier. For above items #1 and #2 refer to Figures C-5a and C-5b for item location.

3. Turn on the three oscilloscopes, allow to warm up for at least 20 minutes and make sure constant current box is turned "OFF". Insure that all BNC cables are connected as per Figure C-4.

4. Prepare specimen to be welded as indicated in Figure C-6. Ascertain velocity probe measures ≈ 95 - 105 Ω before and after being glued down on specimen and after copper ground strip is taped to probe. Take specimen to detonation arena (after being taped together), place in position for test, and measure distance from end of implanted gages to terminal strip. Take specimen back, cut wires this distance, strip insulation, and solder to appropriate terminal ends on gages. See Figures C-4 and C-6 for details and proper polarity.

Drawing not to scale to show details. Entire assembly taped together (not shown).

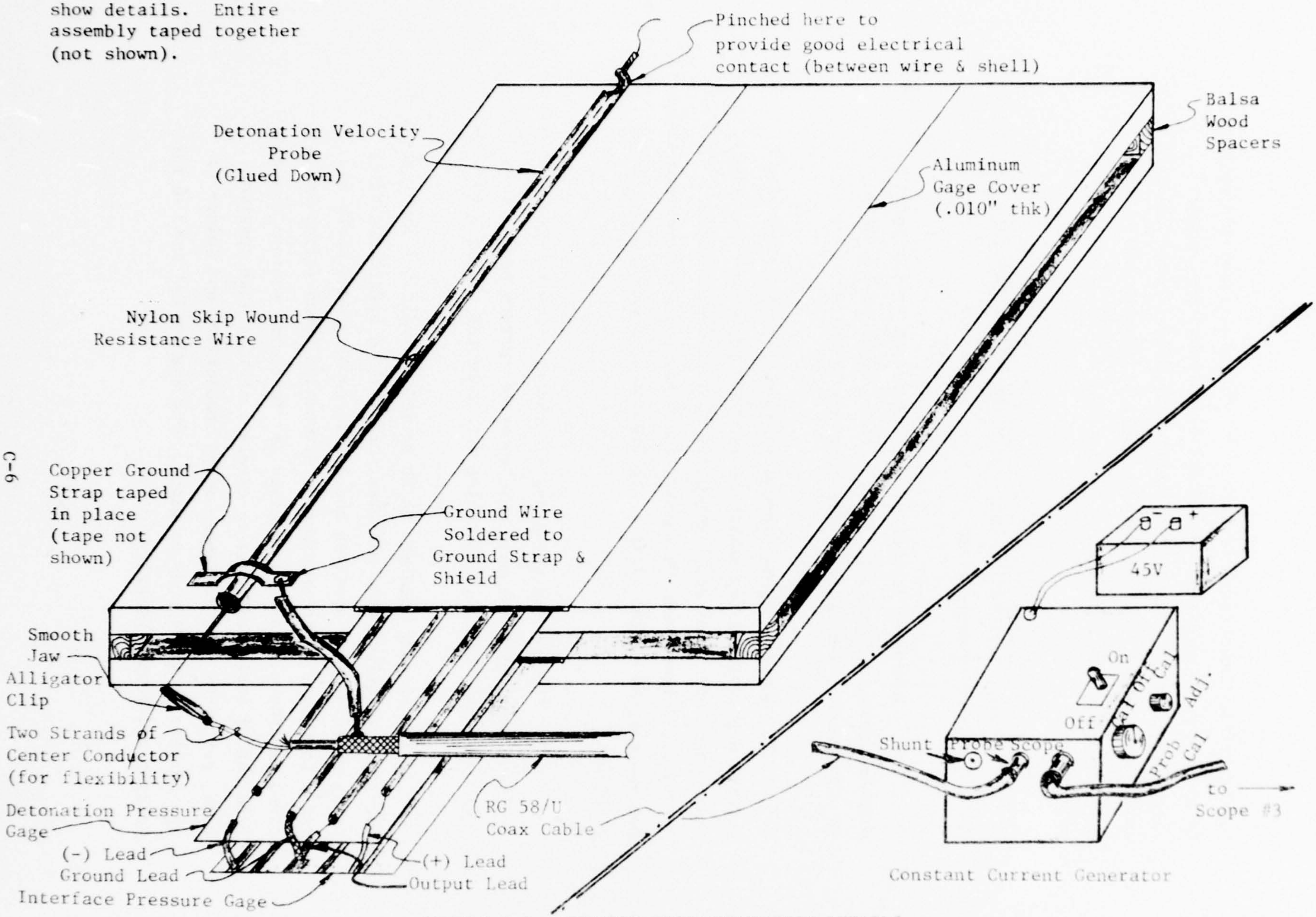


FIGURE C-2 SPECIMEN INSTRUMENTATION DETAILS

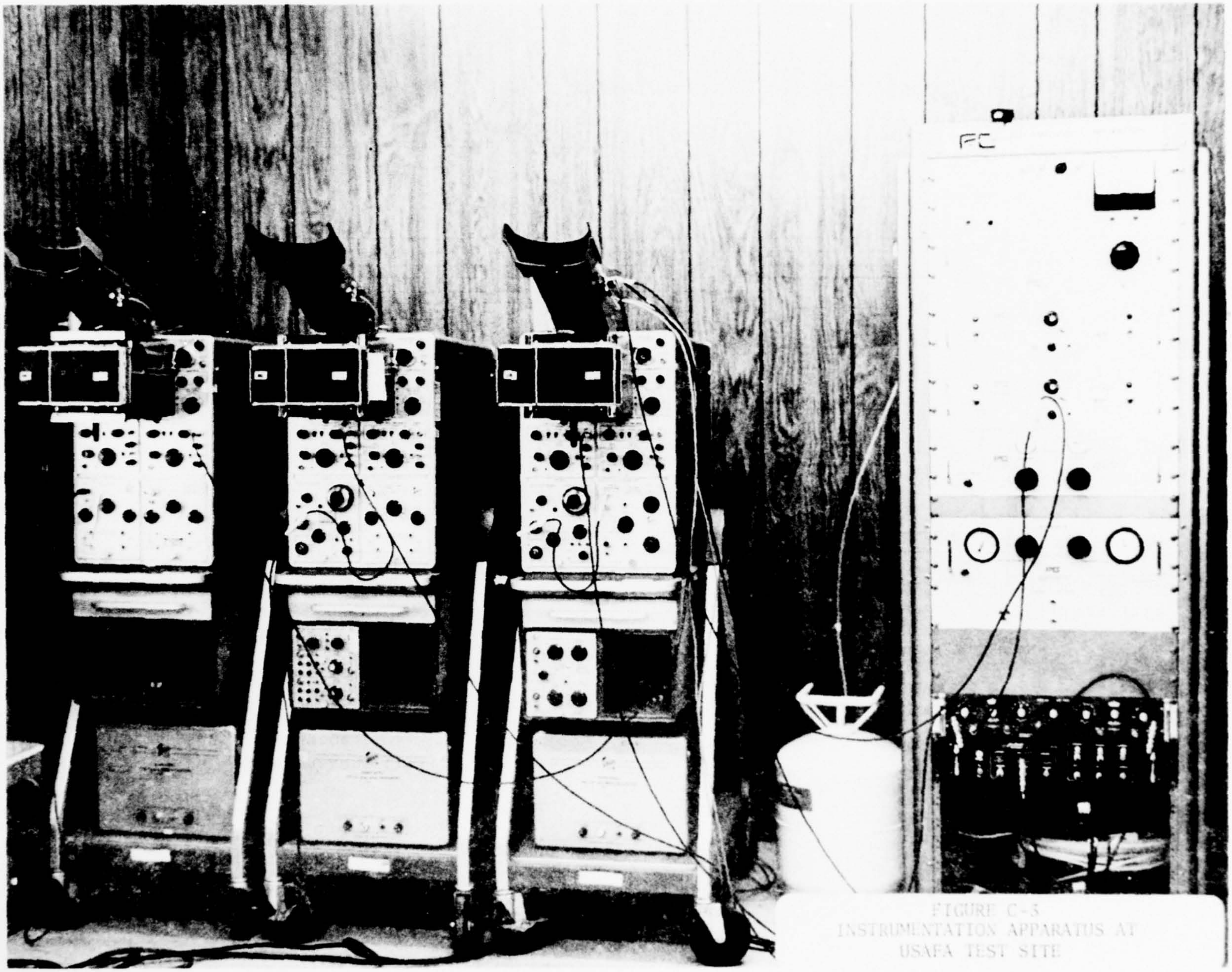
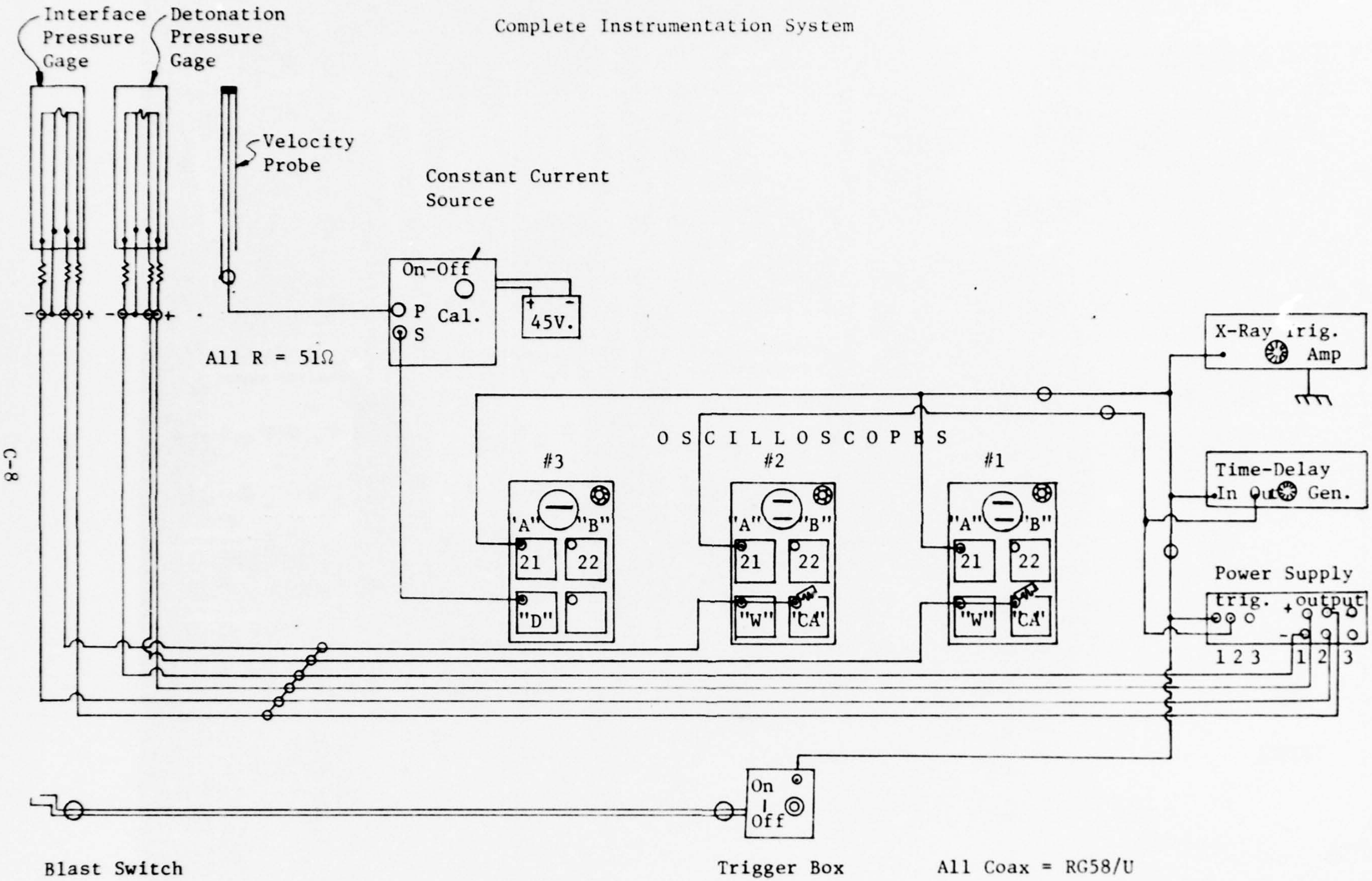


FIGURE C-3
INSTRUMENTATION APPARATUS AT
USAFA TEST SITE

FIGURE C-4

Complete Instrumentation System



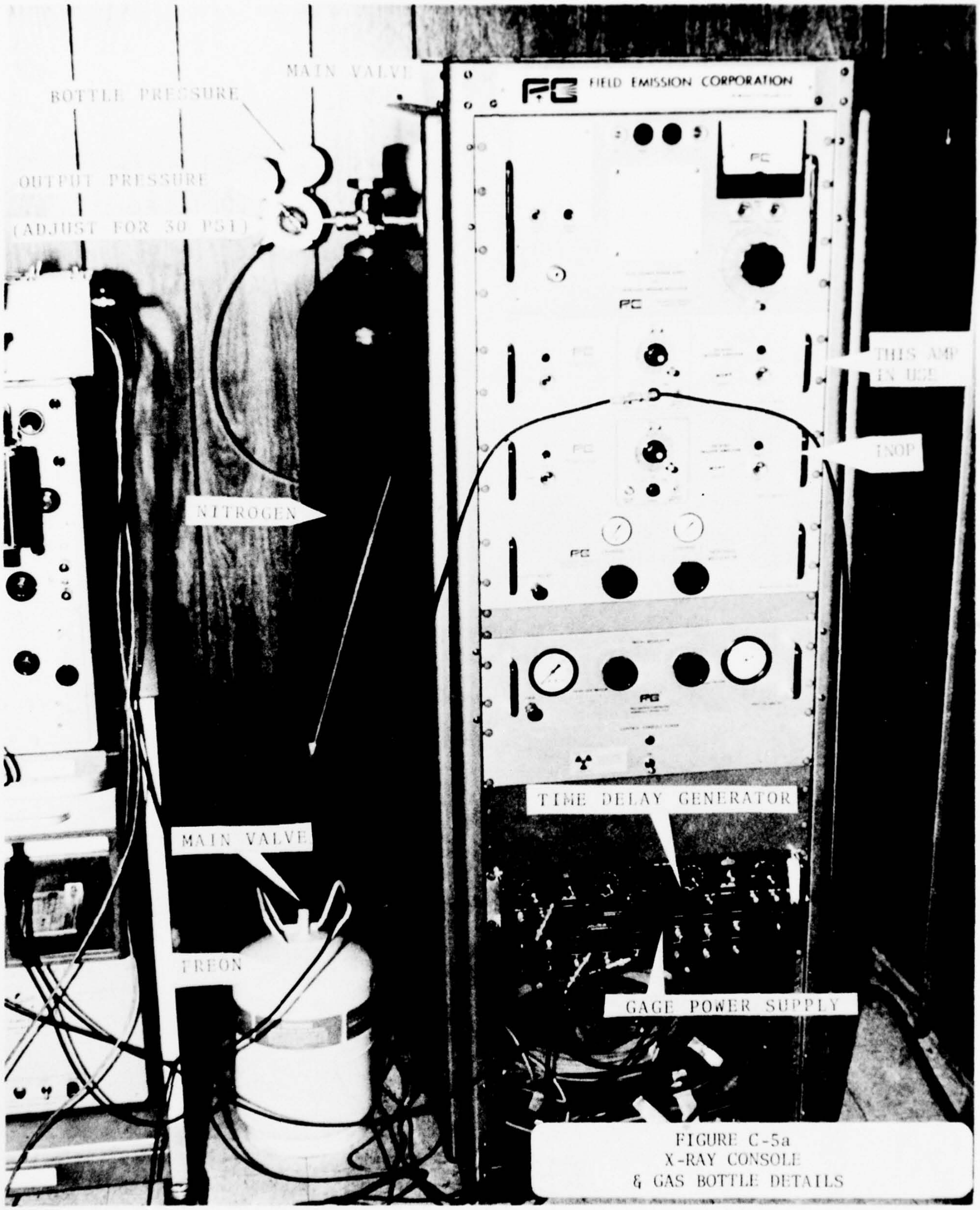


FIGURE C-5a
X-RAY CONSOLE
& GAS BOTTLE DETAILS

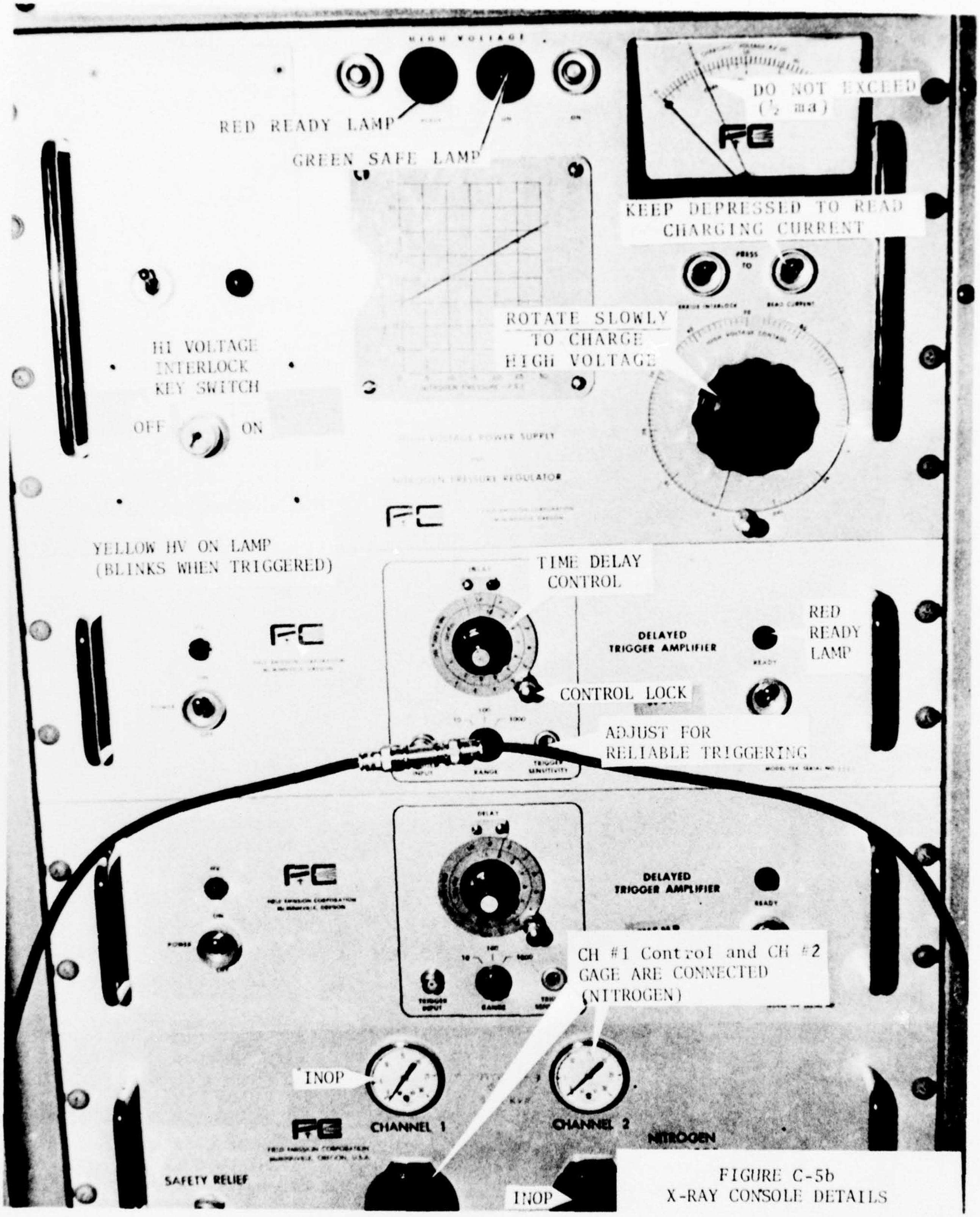


FIGURE C-5b
X-RAY CONSOLE DETAILS

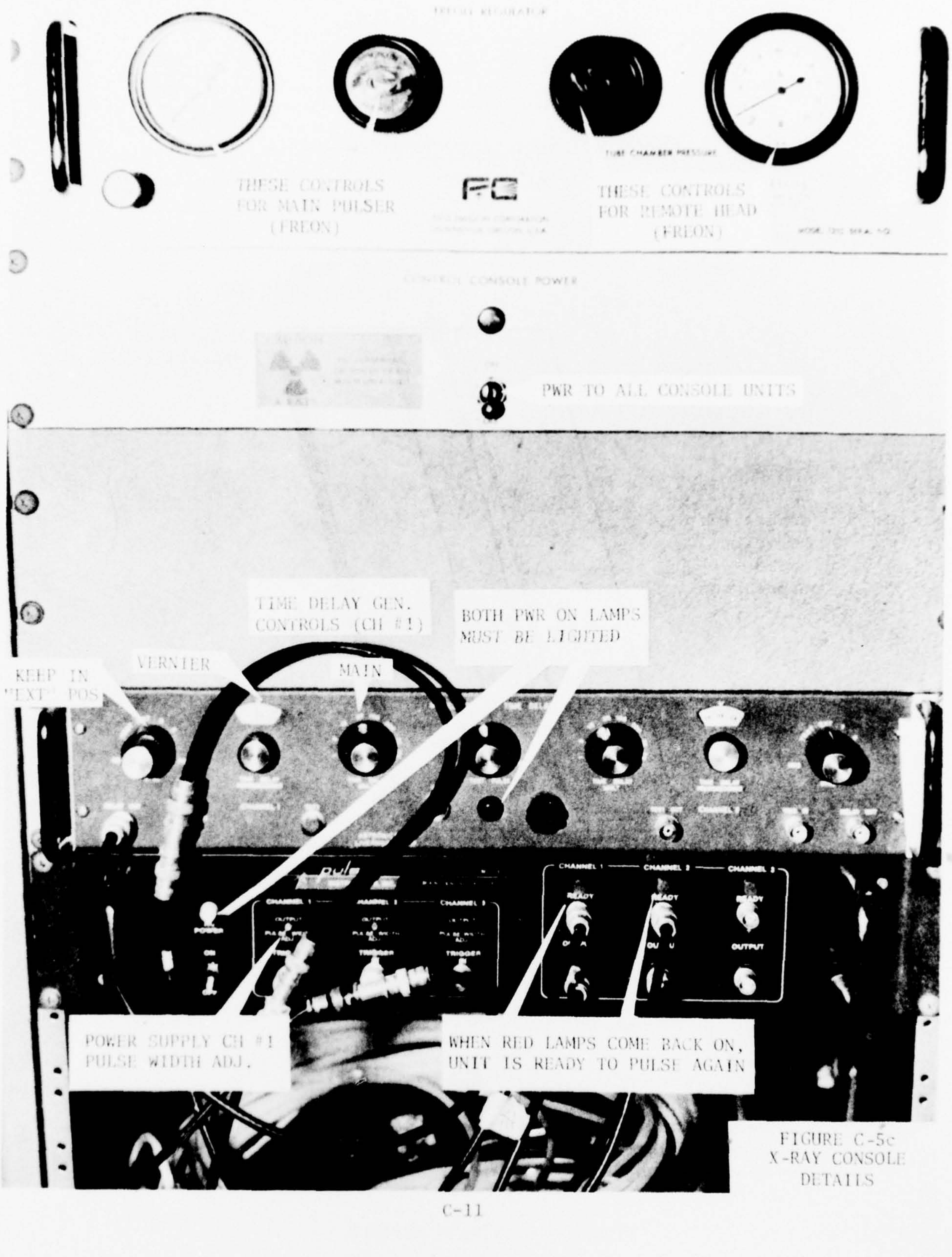


FIGURE C-5c
X-RAY CONSOLE
DETAILS

FIGURE C-6a

ENTIRE ASSEMBLY TAPED TOGETHER

(not shown)

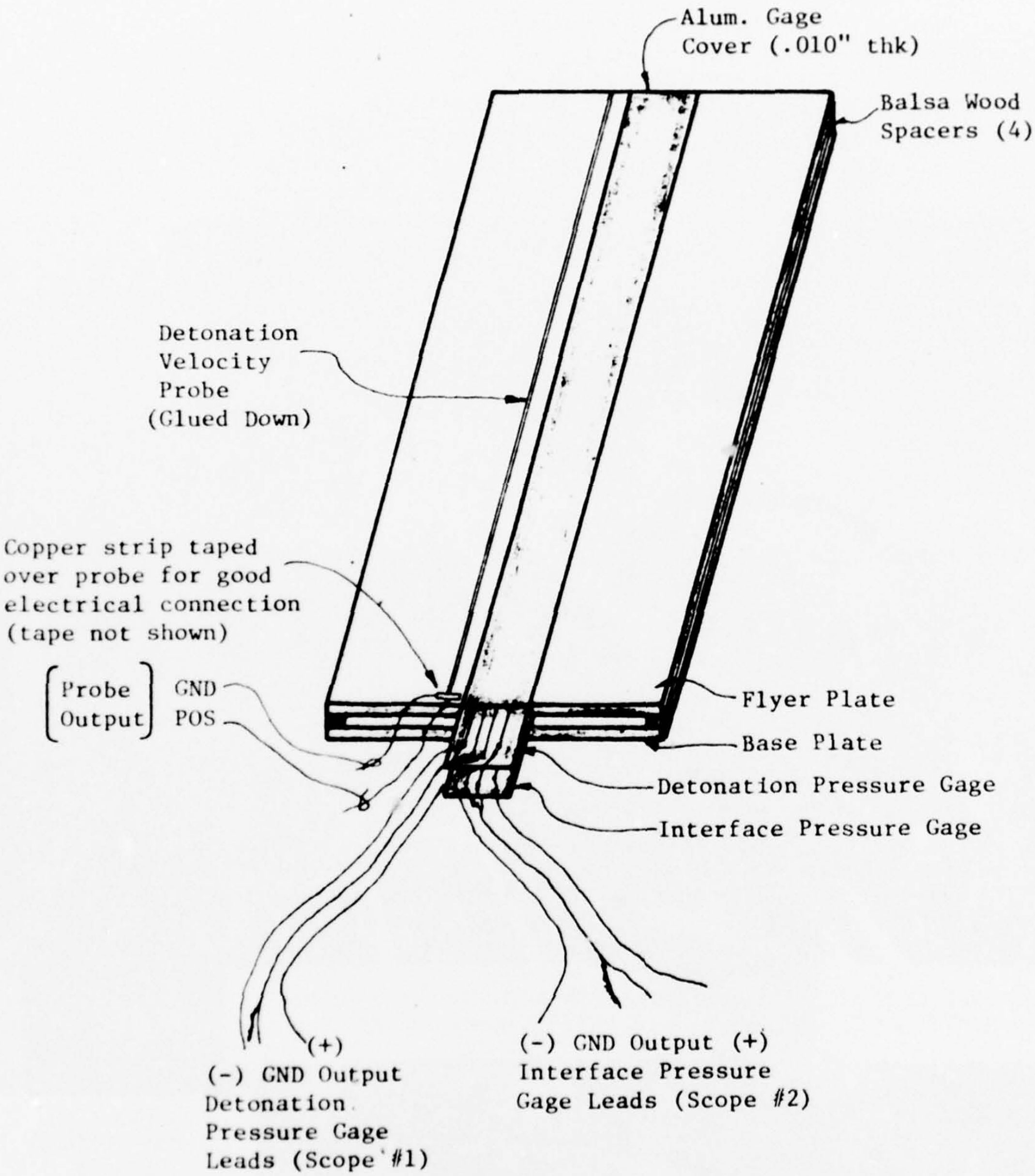


FIGURE C-6 WIRING DETAILS

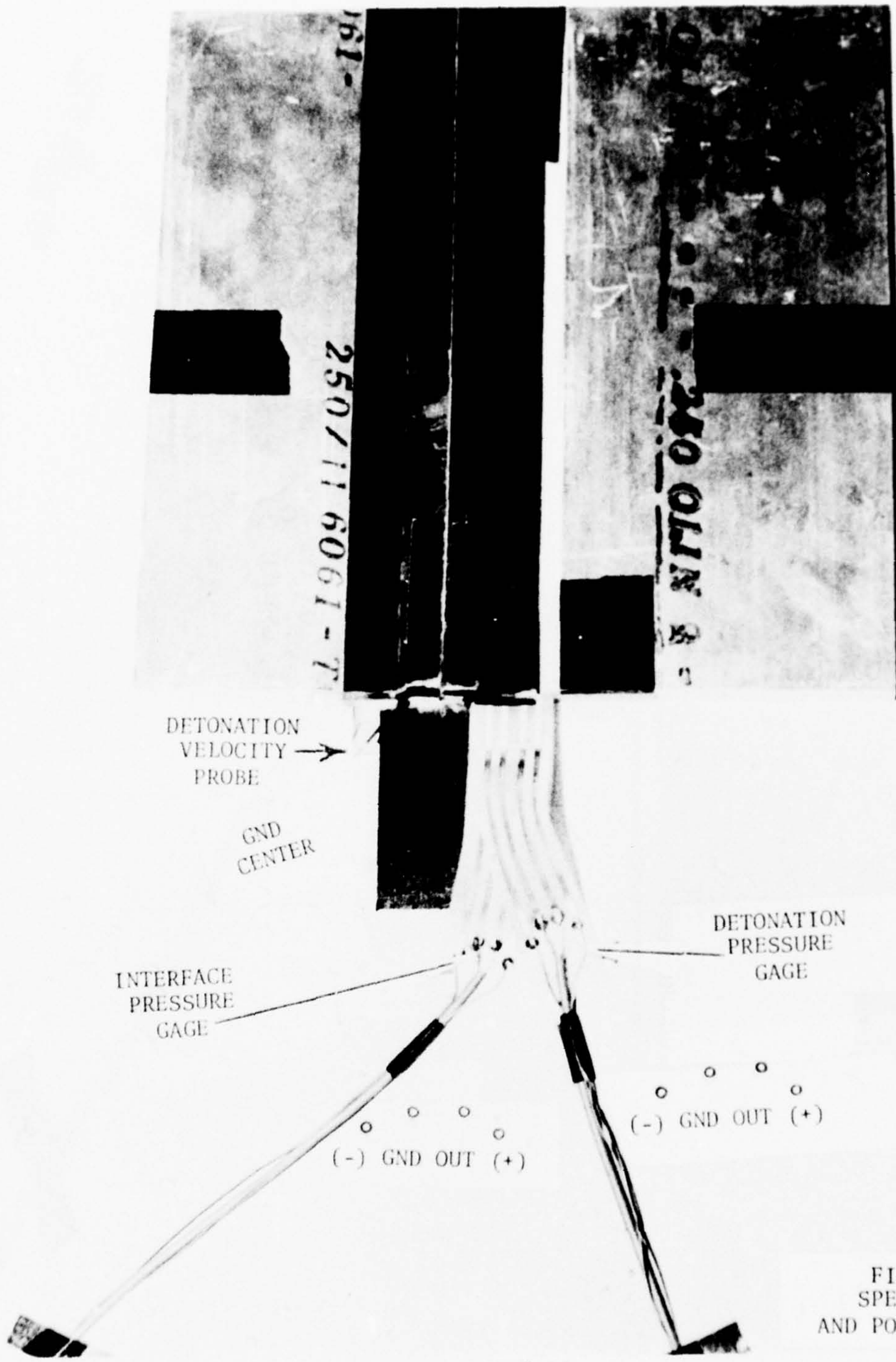


FIGURE C-6b
SPECIMEN WIRING
AND POLARITY DETAILS

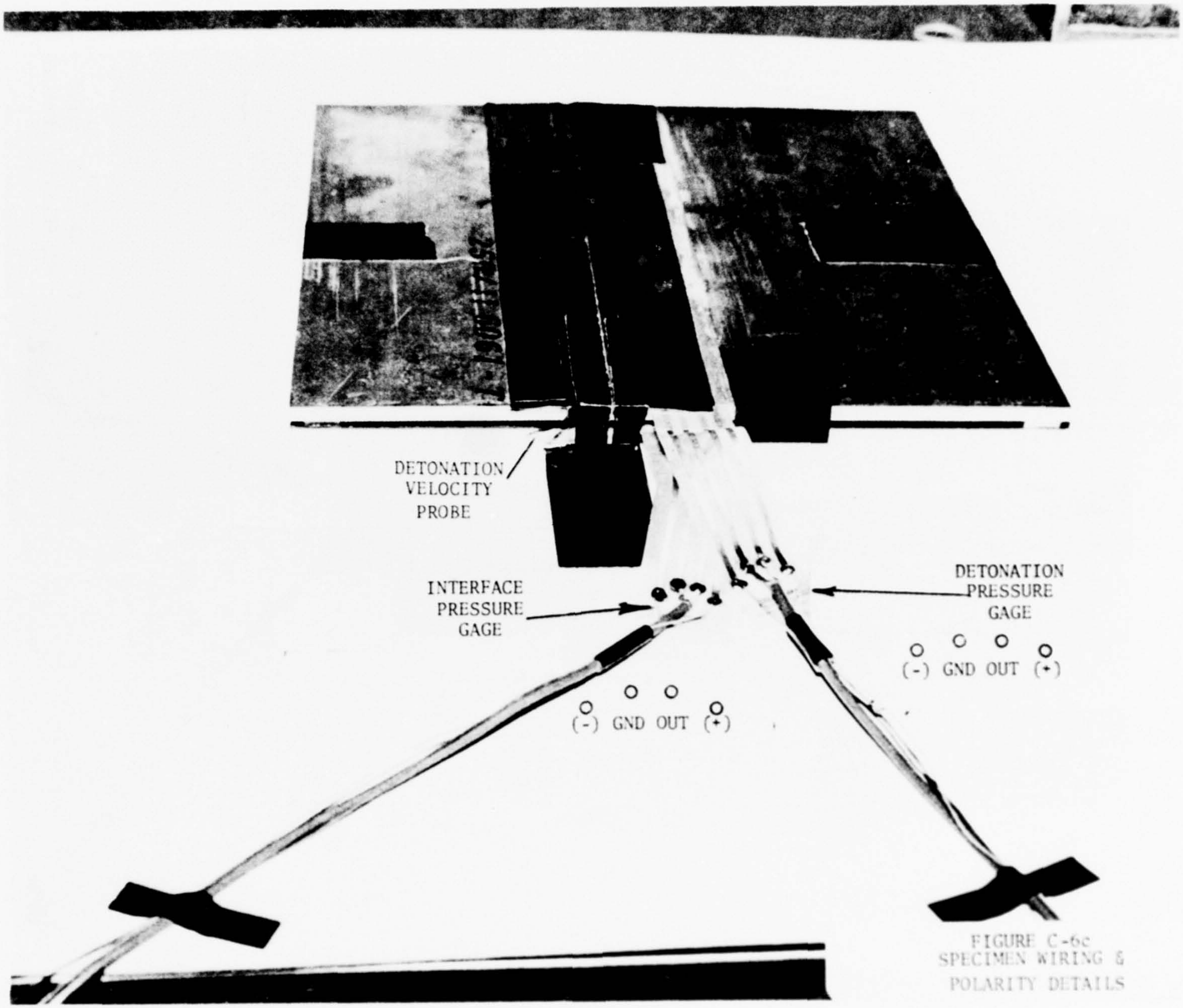


FIGURE C-6c
SPECIMEN WIRING &
POLARITY DETAILS

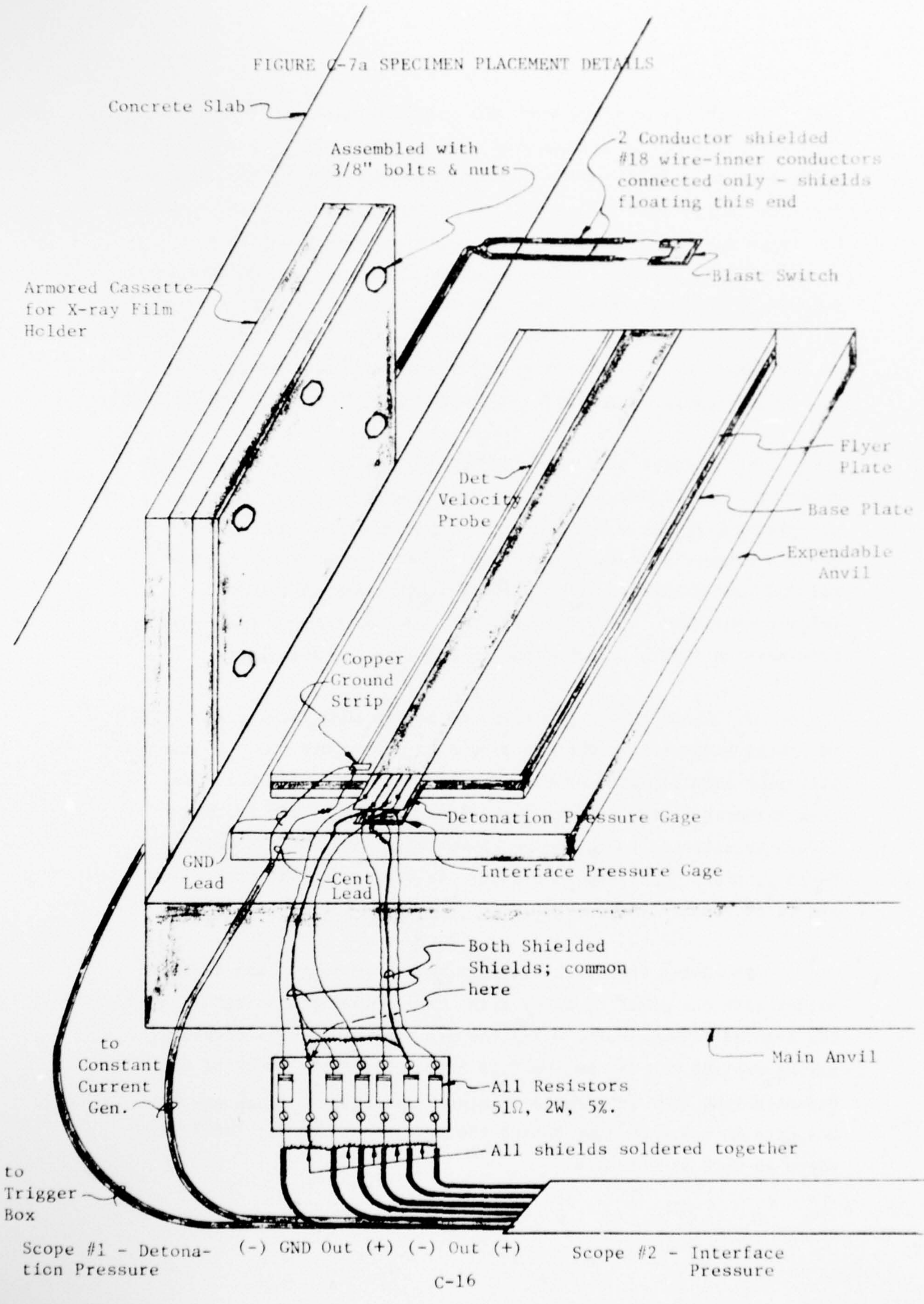
5. Place prepared specimen in proper location for test. This will normally be on opposite side of steel anvil from X-Ray tubehead, and somewhat off center to the right (facing the tubehead) to allow the delayed X-Ray pulse to center upon the colliding plates. All tests must be placed upon one of the expendable anvils to protect the large anvil. Once in place horizontally, temporarily remove the tubehead cover plate and look between the plates at the (+) on the tubehead. This must be plainly visible for a proper X-Ray, and if it is not, adjust the tubehead either up or down accordingly, using pieces of styrofoam. REPLACE TUBEHEAD COVER!

6. Connect gage wires to terminal strip, observing proper polarity. See Figure C-7 for details. Connect blast switch as per Figure C-7, and short terminals together a few times to make certain triggering circuits are O.K. Other person turns trigger box "ON" and observes yellow "High Voltage" lamp on Delayed Trigger Amplifier. (See Figure C-5). Lamp will blink every time terminals on switch are shorted (if there are no problems).

7. Connect Velocity Probe to single COAX line, center wire to center conductor, ground to ground as per figure C-7. A smooth alligator clip is soldered to a few inches of #28 wire which is then soldered to the coax center conductor. This clip is then carefully attached to the probe center wire, and the assembly taped in place. BE SURE no pressure is exerted on the probe, or shorts or "opens" will occur.

8. Using the black cloth film "change bag", load the film holder with one sheet of X-Ray film. Then place the holder in the armored film cassette using the 3/8" nuts and bolts provided, making certain the (+) on the film holder faces the front of the cassette (the 1/8" expendable aluminum face piece). Place the cassette in position just behind the specimen to center the X-Ray photo as much as possible.

FIGURE C-7a SPECIMEN PLACEMENT DETAILS



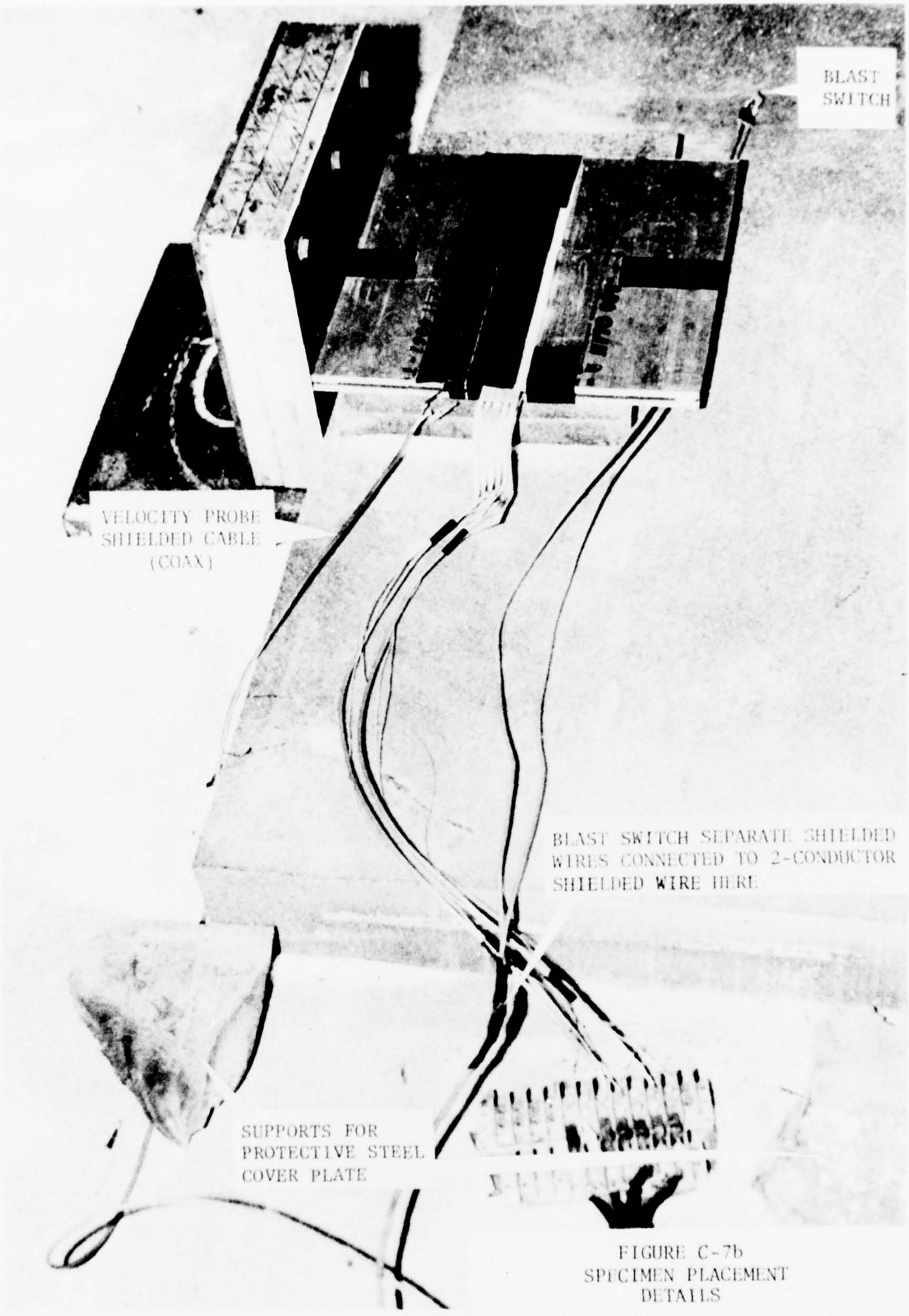


FIGURE C-7b
SPECIMEN PLACEMENT DETAILS

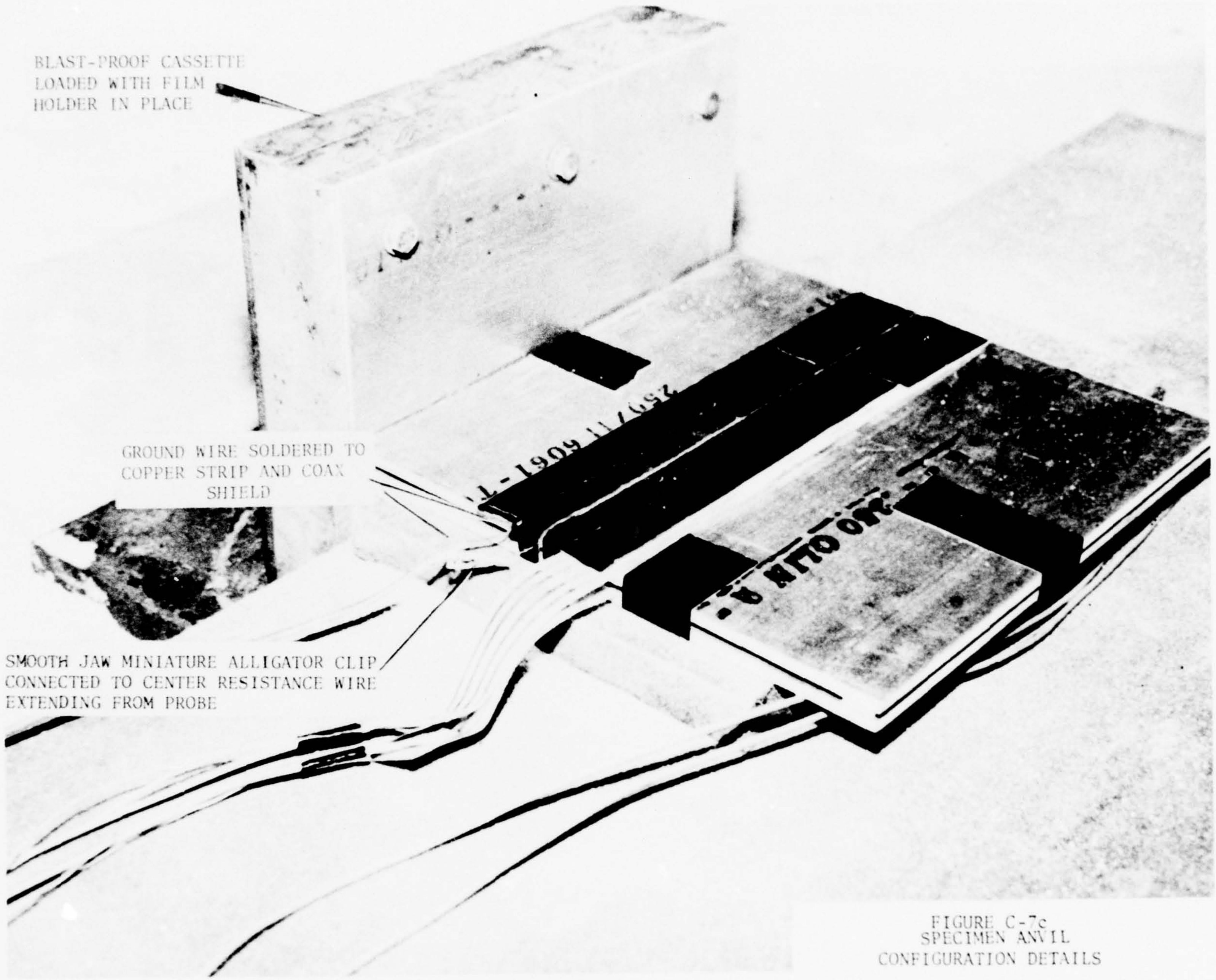


FIGURE C-7c
SPECIMEN ANVIL
CONFIGURATION DETAILS

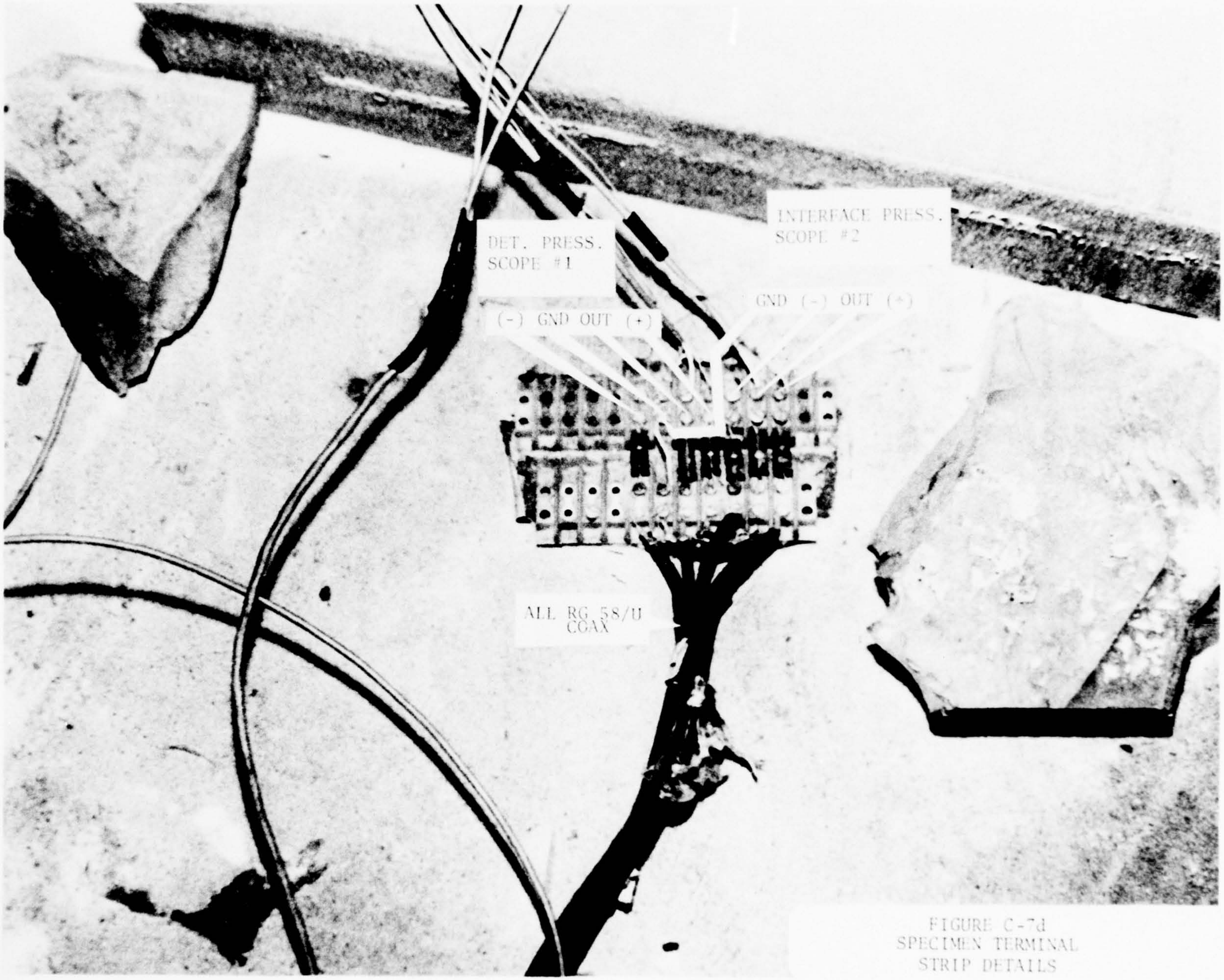


FIGURE C-7d
SPECIMEN TERMINAL
STRIP DETAILS

9. Now load the explosive with line wave generator attached. (See Figure C-8). Tape down the blast switch on a wooden block, and tape the apex of the line wave generator directly over it. This is where the blasting cap will be located.

10. At this point, set up of the experiment is complete; setup and calibration of the electronics now begins. All scope and X-Ray settings should be entered on the check-off sheet provided, for complete data analysis after the test (Figure C-11). Refer to Figure C-9:

a. Set Scope #1 Time Base 21A to single sweep mode.

b. Set Time Base 21A for lower trace and Time Base 22A for upper trace. Set Time Base 22A to "SWEEPS ONCE FOR EACH A DEL'D B TRIG".

c. Set both "W" and "L" plug in amps to "DC Coupled" (Input Attenuation Control).

d. Set "W" controls as follows:

Display = A - V_c	Comparison Voltage = 0.000
V_c RANGE = +11	Millivolts/cm = 50

e. Set "L" controls as follows:

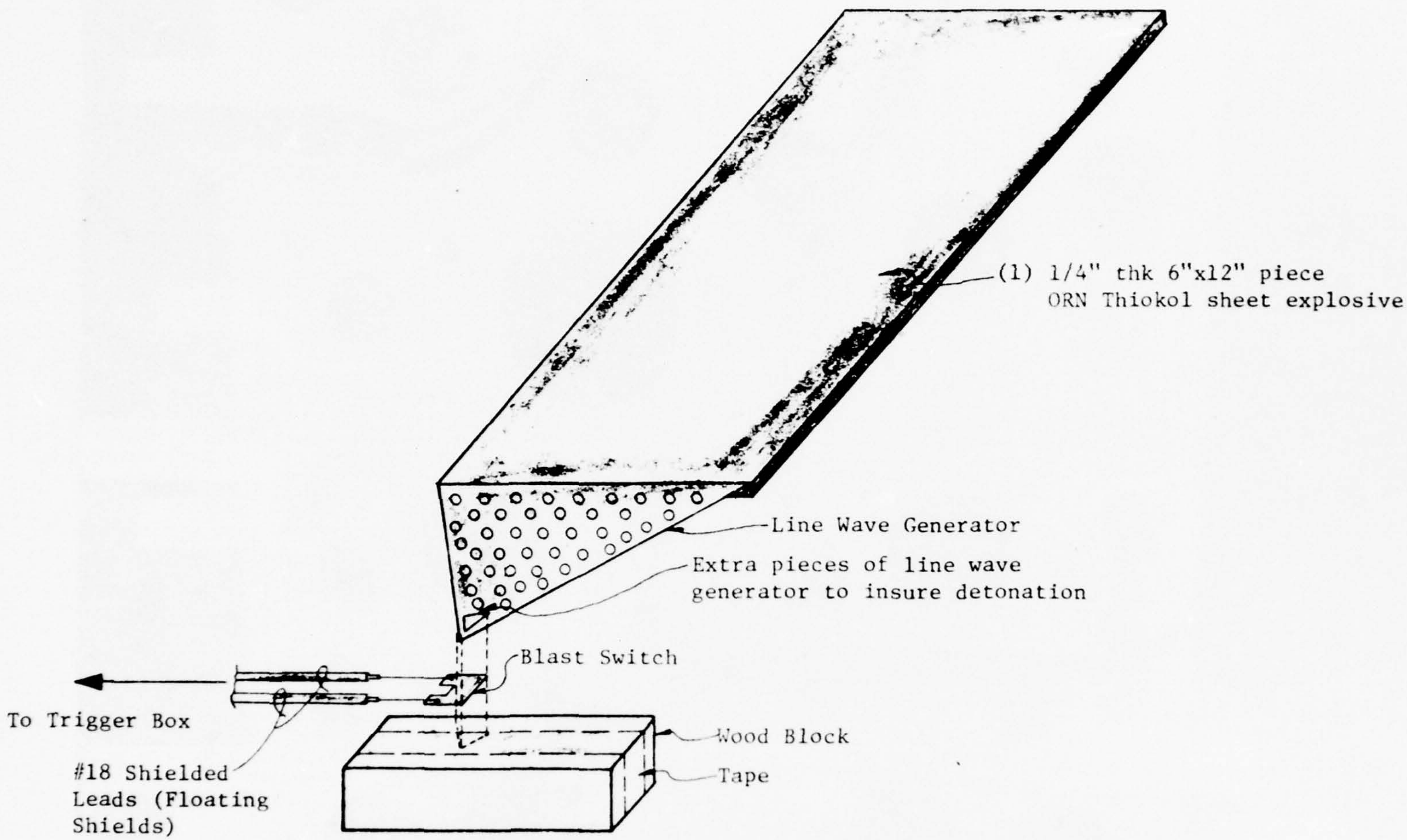
INPUT = "AC"
VOLTS/cm = 1 V/cm

f. Set Time Base #21A controls as follows:

SLOPE = +	SWEEP = SINGLE SWEEP
COUPLING = AC	TIME/cm = 10 μ volts/cm
SOURCE = EXT	

FIGURE C-8 EXPLOSIVE DETAILS

Explosive set on top of specimen, then blast switch taped to wood block and apex of line wave generator taped directly over blast switch. Cap will be taped into place directly on top of apex.



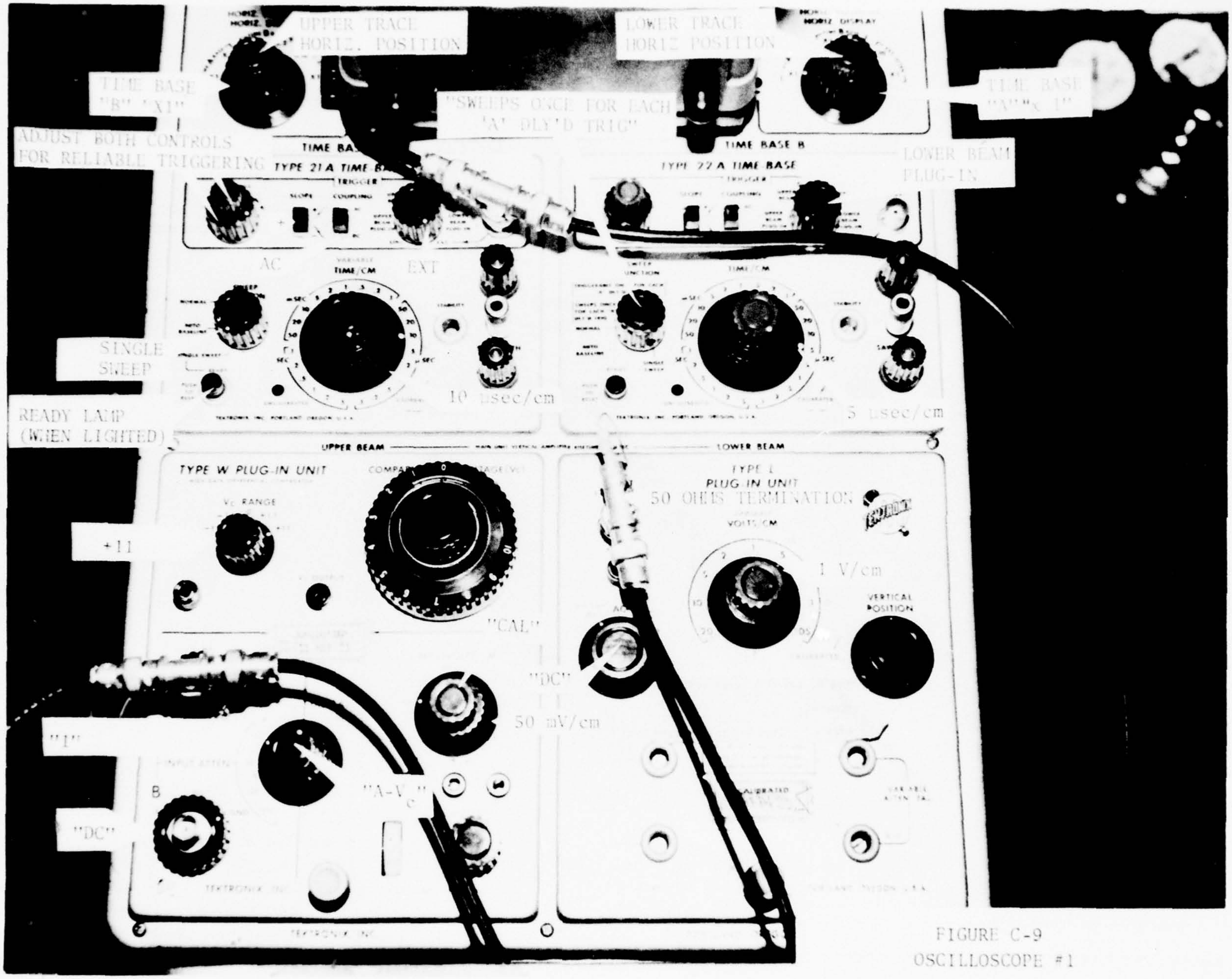


FIGURE C-9
OSCILLOSCOPE #1

TRIG LEVEL = set so reset
lamp remains lit until deliberately triggered

g. Set Time Base #22A controls as follows:

SLOPE = +

COUPLING = AC

SOURCE = LOWER PLUG IN

TIME/cm = 5 μ volts/cm

SWEEP = SWEEPS ONCE FOR EACH A DEL'YD B TRIG

TRIG LEVEL Same as for #21

11. Turn trigger box "ON". Every time push button is depressed both top and bottom scope traces will sweep. (After each sweep reset button on scope must be depressed and will stay lighted until trace is triggered)

12. Temporarily change "input Atten. "to "GND". Now operate the "Intensity", "Focus", "Astigmatism", and "Vertical" and "Horizontal" position controls to place the bottom trace (dot) on the bottom line of the graticule at the left-hand edge ("L" plug in). Now operate similar controls relative to the "W" plug in, and place the trace (dot) on the 4th line down from the top and at the left-hand edge. Check these adjustments several times to be sure there is no appreciable drift especially with the top trace. Screen illumination and top trace intensity are very important and must be carefully balanced so that the pressure peak will have as much contrast as possible. Pencil marks have been made next to the Screen illumination and trace intensity controls for optimum settings and should be followed.

13. Now, change "Input Atten." to "DC" and operate the scope reset button; then operate the trigger box push button while observing the bottom trace. A "step" similar to that of Figure #9a should be observed. At this point, using a small screwdriver, adjust the pulse width control on channel #1 of the Pulsar Power

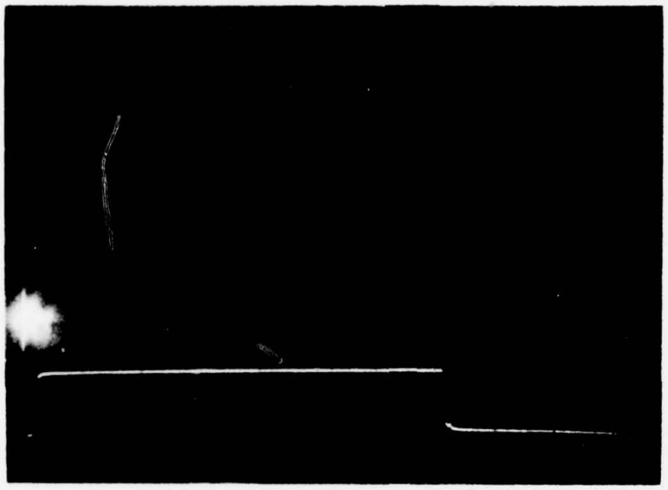
Supply (See Figure C-5) to obtain a pulse length of about 7 cm (70 μsec). Also, do not pulse the Power Supply more than about six times per minute.

14. Move the "Input Atten" setting on the "W" plug-in back to the "DC" position. After observing about how high the "step" on the bottom trace is (usually about 1.200V), dial that much in on the Comparison Voltage dial (V_c). This should bring the top of the step onto the scope face (TOP TRACE). Then carefully adjust for more or less V_c to bring the top trace down as close as possible to the top trace base line (4th line down from top). Enter these values as noted on the test checkoff sheet.

15. Set the time delay vernier dial for the proper amount of time delay. Each major division corresponds to 10 microseconds at this sweep rate (10 μsec/cm on the BOTTOM TRACE). Since there is an effective 50 μsec "window" on the top trace, the time delay should be adjusted to try to center the expected detonation stress pulse in this "window". To the total amount of time for the explosive to burn to the top gage must be added about 16 μsec/inch, burning time for the line wave generator. For an average value of 3000 m/s detonation velocity one can calculate about 10 μsec/inch, to which must always be added the 16 μsec line wave generator burning time. If the detonation pressure gage is located 4 in. down the plate, for example, one could expect the pulse to arrive at about 56 μsec from time T = 0. To center the top trace "window" at about 55 or 56 μsec, one would need to dial in about 30 μsec time delay into scope #1. For a typical result see Figure C-10c.

16. Insure that both inputs to Scope #2 are in "GND" position, and proceed to "baseline" both traces in the same manner as with Scope #1. Once baselined and stable, set inputs to "DC position and locate top trace in the same manner as with Scope #1.

FIGURE C-10
OSCILLOSCOPES #1 & #2



TOP TRACE

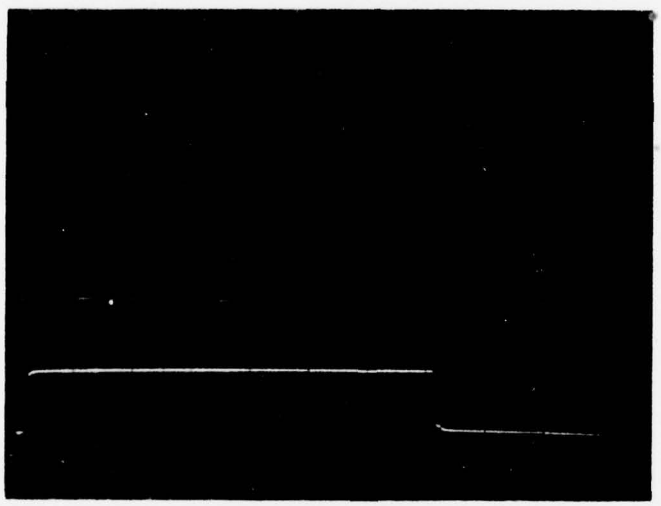
VERT = 50 mV/cm
HORIZ = 5 μsec/cm

BOTTOM TRACE

VERT = 1 V/cm
HORIZ = 10 μsec/cm
PULSE
WIDTH ≈ 70.2 μsec
PULSE
HEIGHT ≈ 1.2 V

TIME
DELAY = 30 μsec
(TOP TRACE)

FIGURE C-10a - SET UP FOR BOTTOM TRACE



TOP TRACE

VERT = 50 mV/cm
HORIZ = 5 μsec/cm
BASELINE
DIFF ≈ 0.3 cm

BOTTOM TRACE

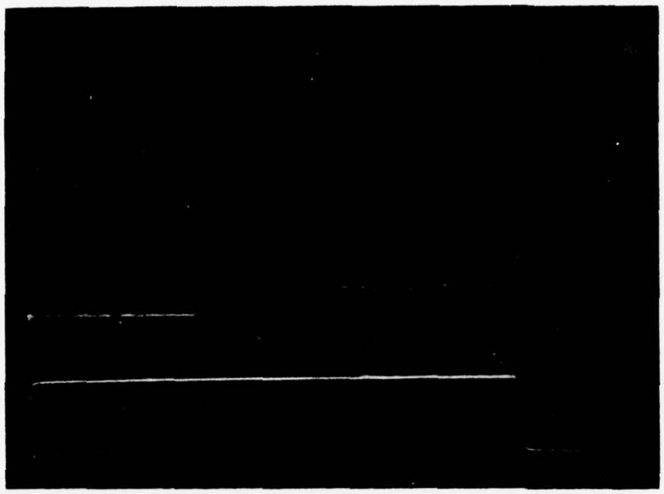
VERT = 1V/cm
HORIZ = 10 μsec/cm
PULSE
WIDTH ≈ 70.2 μsec
PULSE
HEIGHT ≈ 1.2 V

TIME
DELAY = 30 μsec
(TOP TRACE)

VOLTAGE OFFSET
(V_c) = 1.185 v

FIGURE C-10b - SET UP FOR TOP TRACE

FIGURE C-10
OSCILLOSCOPES #1 & #2 (Contd)



TOP TRACE

VERT = 50 mV/cm
HORIZ = 5 μsec/cm

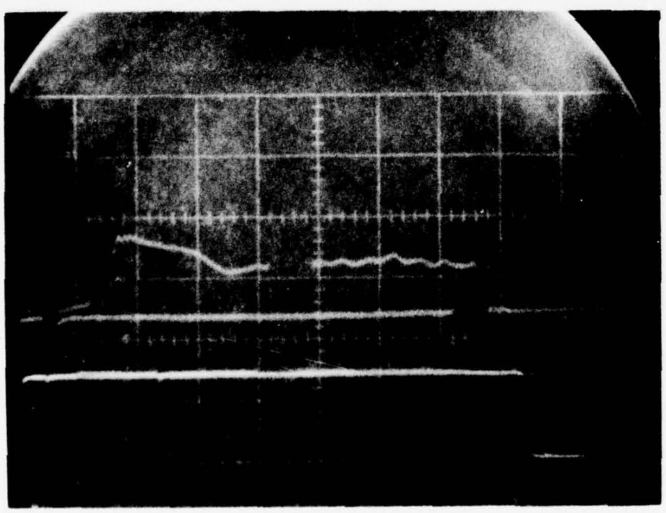
BOTTOM TRACE

VERT = 1 V/cm
HORIZ = 10 μsec/cm
PULSE
WIDTH ≃ 80 μsec
PULSE
HEIGHT ≃ 1.25 V

V_c = 1.235 v

TIME
DELAY = 40 μsec
(TOP TRACE)

FIGURE C-10c - DETONATION PRESSURE PULSE PHOTO
(PHOTO WAS **PRE**-BASELINED)



TOP TRACE

VERT = 50 mV/cm
HORIZ = 5 μsec/cm

BOTTOM TRACE

VERT = 1 V/cm
HORIZ = 10 μsec/cm
PULSE
WIDTH ≃ 80.4 μsec
PULSE
HEIGHT ≃ 1.4 V

V_c = 1.384 V

TIME
DELAY ≃ 2 μsec
(TOP TRACE)

TIME DELAY (FROM T = 0
BY TIME DELAY GEN = 80 μsec

FIGURE C-10d - INTERFACE PRESSURE PULSE PHOTO
(PHOTO WAS PRE-BASELINED)

FIGURE C-11

FINAL CHECKLIST FOR QUADRUPLE
INSTRUMENT SHOT

USAFA EXPERIMENT # ______

A. Before assembling specimen on firing table, insure that each trigger line triggers its respective devices at least 10 times consecutively.

B. Inspect all cables for cuts and bruises, and insure maximum separation from Flash X-Ray leads. Insure proper cable connections at arena.

C. After assembling specimen on firing table, insure that specimen is properly positioned for X-Ray shot. Insure that "X" on tube cover face can be seen by looking between plates of specimen.

D. Install assembled armored cassette in proper position.

E. INSTALL PROTECTIVE COVER PLATE OVER TUBE HEAD!

F. Have initiation device connected; FIRING CIRCUIT "READY"; and firing switch close at hand in instrumentation facility.

CHECK LIST

1. Insure three scope cameras are operational and contain film.

2. Insure flash X-Ray gas pressures are correct and that trigger lamp and hi-voltage lamp are lit.

3. Inspect all settings on scope #1 for correctness. Insure time delay is proper value. Insure proper connections.

4. Pulse first channel of Pulsor with trigger box. Insure that pulse appears on bottom trace. Zero both traces several times to insure minimum baseline error.

5. Repeat triggering of Pulsor and dial in offset voltage on "W" plug-in amp until top of pulse appears in top window. Carefully adjust until top of pulse is as close as practicable to upper trace baseline. At this time, enter the following values:

FIGURE C-11 (Contd)

UPPER TRACE

A. VERTICAL SCALE:

B. HORIZONTAL SCALE:

C. OFFSET VOLTAGE AS INDICATED ON DIAL:

D. DISTANCE BETWEEN TOP OF PULSE AND UPPER TRACE BASELINE:

E. TIME DELAY AS INDICATED ON DIAL:

LOWER TRACE

G. VERTICAL SCALE:

H. HORIZONTAL SCALE:

I. HEIGHT OF PULSE:

J. LENGTH OF PULSE:

K. TIME DELAY FROM TIME ZERO IF USED:

L. DISTANCE OF PRESSURE GUAGE FROM INITIATION END OF SPECIMEN:

6. Inspect all settings on Scope #2 for correctness. Insure time delay is proper value. Insure proper connections.

7. Pulse second channel of Pulsor with trigger box. Insure that pulse appears on bottom trace. Zero both traces several times to insure minimum baseline error.

8. Repeat triggering of Pulsor and dial in offset voltage on "W" plug-in amp until top of pulse appears in top window. Carefully adjust until top of pulse is as close as practicable to upper trace baseline. At this time, enter the following values:

UPPER TRACE

A. VERTICAL SCALE:

B. HORIZONTAL SCALE:

C. OFFSET VOLTAGE AS INDICATED ON DIAL:

FIGURE C-11 (Contd)

D. DISTANCE BETWEEN TOP OF PULSE AND UPPER TRACE BASELINE:

E. TIME DELAY AS INDICATED ON DIAL:

LOWER TRACE

F. VERTICAL SCALE:

G. HORIZONTAL SCALE:

H. HEIGHT OF PULSE:

I. LENGTH OF PULSE:

J. DISTANCE OF INTERFACE PRESSURE GUAGE FROM INITIATION END OF SPECIMEN:

NOTE: ABTRONICS TIME DELAY ___________

9. Inspect all settings on Scope #3 for correctness. Insure proper connections.

A. VELOCITY PROBE CABLE TO "PROBE" ON CONSTANT CURRENT BOX

B. "SCOPE" OUTPUT TO SCOPE INPUT

C. SCOPE SET ON EXTERNAL TRIGGER

D. SET VERT. SCALE TO 2V/CM AND HORIZONTAL SCALE TO 10 M SEC/CM. IF ANOTHER VALUE FOR HORIZONTAL SETTING, ENTER HERE ___________.

10. With Box Switch in "OFF" position, baseline scope trace several times to insure minimum baseline error.

11. MEASURE VELOCITY PROBE CABLE BETWEEN CENTER AND GROUND. SHOULD BE IN VICINITY OF 100-150 OHMS. IF MARKEDLY DIFFERENT FROM THIS, RESET FIRING CIRCUIT SAFETY SWITCHES, AND REINSPECT PROBE AT SPECIMEN, AND REPAIR AS NECESSARY.

12. Turn box switch to "ON", setting to "CALIBRATE"; and adjust potentio-meter so that the trace moves up exactly 4 CM from baseline when the switch is turned on. INSURE

FIGURE C-11 (Contd)

THAT RESET LAMP REMAINS LIT UNTIL TRIGGERED BY TRIGGER BOX.

13. Turn switch "OFF"; turn setting to "PROBE"; reactivate switch and insure that trace moves up at approximately the 4 CM, depending on the length of the probe.

14. Return to X-Ray console; recheck both gas pressures for correctness; time delay for proper setting; and insure again that trigger and High Voltage lamps are lit. Enter the following at this time:

A. FREON PRESSURE:

B. NITROGEN PRESSURE

C. TIME DELAY SETTING:

15. Return to scope #1; recheck both traces for proper operation. Make sure bottom trace brightness is turned down just out of sight. Insure that screen illumination is turned down to the mark on the scope. Insure "RESET" button is lit.

16. CLOSE #1 CAMERA VIEWING PORT!

17. Return to Scope #2; recheck both traces for proper operation. Make sure bottom trace brightness is turned down just out of sight. Insure that screen illumination is turned down to the mark on the scope. Insure "RESET" button is lit.

18. CLOSE #2 CAMERA VIEWING PORT!

19. Return to Scope #3; recheck to see that scope triggers properly. Make sure trace brightness is turned down just out of sight. Insure that screen illumination is turned down to the mark on the scope.

20. CLOSE #3 CAMERA VIEWING PORT!

21. BASELINE SCOPES #1 & #2!

22. Activate High Voltage and charge X-Ray to proper voltage, being careful to charge slowly to preclude prefires.

23. TURN CONSTANT-CURRENT BOX SWITCH "ON".

FIGURE C-11 (Contd)

24. ACTIVATE "RESET" BUTTON.

25. OPEN #3 CAMERA SHUTTER.

26. OPEN #2 CAMERA SHUTTER.

27. OPEN #1 CAMERA SHUTTER.

28. Glance at all equipment; insure that all three scope reset buttons are lit, and that X-Ray is charged and both lamps on trigger amplifier are lit. Insure three lamps on pulsor are lit.

29. GIVE WARNING AND PRESS FIRING CIRCUIT SWITCH.

30. CLOSE ALL 3 CAMERA SHUTTERS.

31. Operate red button on #1 camera; lift cutter bar slightly; grasp paper firmly, and pull out to stop -- discard paper.

32. Repeat step #30 for #2 camera.

33. Repeat step #30 for #3 camera.

34. Turn high-voltage dial on X-Ray console down to ZERO. Turn "READY" switch on trigger amplifier "OFF".

35. After count of about "15" from start of film developing procedures, open cameras, retrieve photos, and <u>coat</u> with fixing chemical provided.

36. When photos are dry, enter appropriate data on backs.

37. Perform POST-SHOT cleanup tasks.

38. TURN <u>OFF</u> BOTH CHANNELS OF TRIGGER BOX.

39. TURN SWITCH ON CONSTANT CURRENT BOX "OFF".

<u>SPECIMEN DATA</u>

40. THICKNESS

41. STANDOFF DISTANCE

42. LOADING

FIGURE C-11 (Contd)

43. TYPE OF EXPLOSIVE

44. REMARKS

17. The time delay for Scope #2 is somewhat different. The time delay dial has been set at perhaps one or two microseconds. (Just enough to insure proper operation of the delay circuits), and all the delay necessary has been dialed into the Abtronics time delay generator. With the top and bottom traces coming on at essentially the same time, the time delay generator can be set to center the interface pressure pulse on the top trace of Scope #2. The interface pressure pulse can be expected to arrive at the interface gage anywhere from 20 to perhaps 50 μsec later than the time needed just for the additional distance. This is caused by the plate stand-off distance, plate thickness, etc. With a distance of 6 in down the plate for the interface gage, using 1/4" thick 6061-T6 aluminum plates, the interface pulse has been appearing at about 80 to 90 μsec from T = 0. Therefore a good delay is 60 μsec for the time delay generator. (Assuming 3000 m/s detonation velocity).

18. Since "spikes" are produced on the power supply "step" pulse when the time dealy generator, power supply, and Flash X-Ray fire, the various delay times need to additionally reflect some planning in keeping the areas where both detonation and interface stress pulses are expected as free as possible from any interference. The "spikes" produced from these instruments are of a sufficient magnitude to obliterate the stress pulses, if superimposed thereon. The Flash X-Ray produces such a large interference pattern (A damped oscillation of 1 or 2 volts peak-to-peak and perhaps 10μsec long), that it has been set to fire after both stress pulses have been recorded.

19. The next step in the set-up of the electronics is Scope #3. (Refer to Figure C-12). It uses only the top trace (Plug in "L" with time base #21A) and is triggered at T = 0

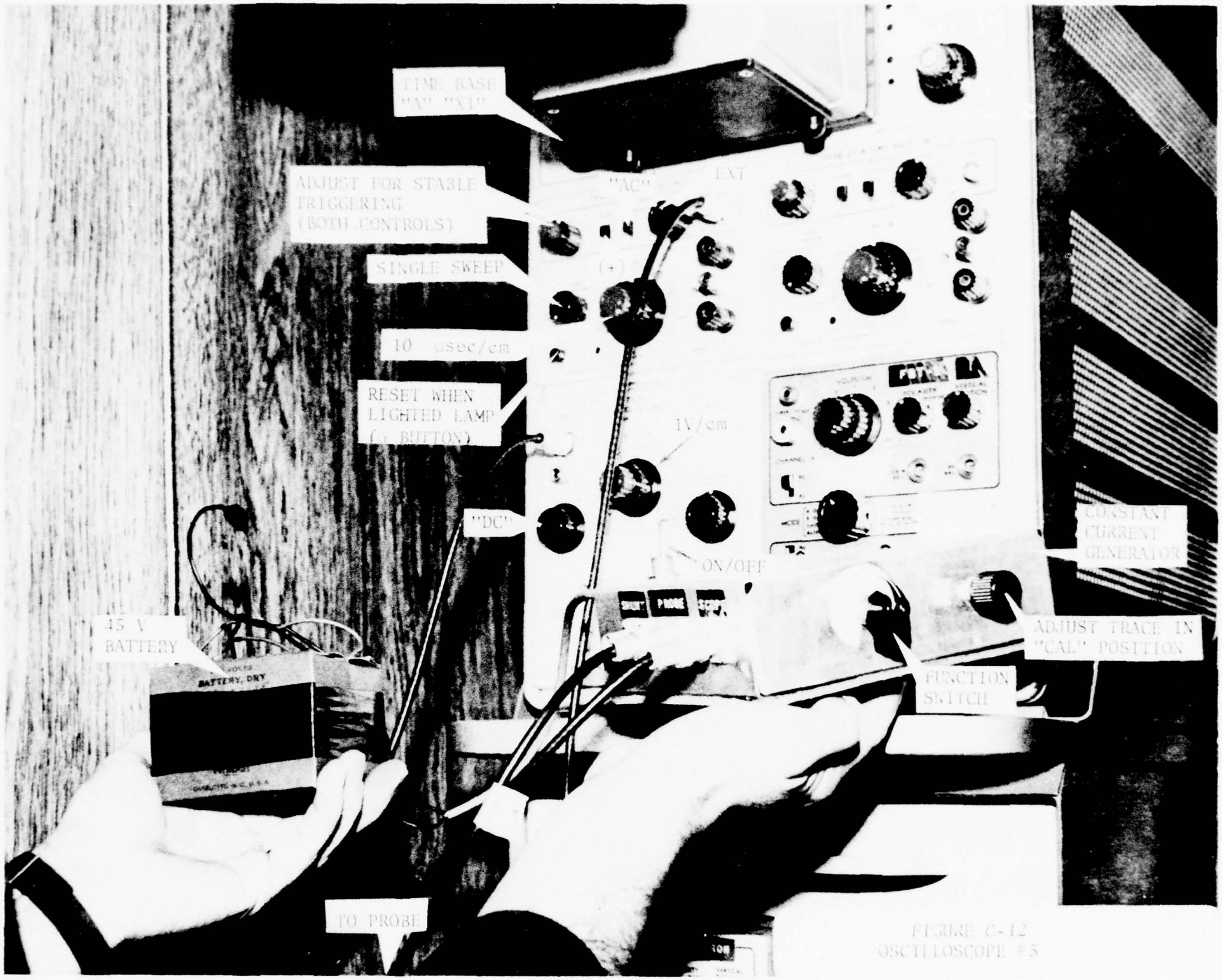


FIGURE C-12
OSCILLOSCOPE #3

directly from the trigger box. The following settings are made:

TIME BASE 21A = UPPER BEAM

SLOPE = +	TIME /cm = 10 μsec/cm
COUPLING = AC	TRIGGER LEVEL = set so reset lamp remains lit until deliberately triggered
SOURCE = EXT	
SWEEP = SINGLE SWEEP	
	PLUG IN "D"
	INPUT = DC
	VOLTS/cm = 2 V/cm

a. With the constant current generator still in the off position, and using the Intensity, Focus, Astigmatism, and vertical and horizontal centering controls, center the top trace of Scope #3 on the 4th line down from the top of the graticule, and at the left hand edge. Now put the constant-current box in the "CAL" position and turn the box to "ON". The trace should immediately rise to about the top of the graticule. Using the adjustment control, set the trace exactly on the top line of the graticule. Turn the box off; the trace should fall back to the 4th line down. Now set the box to "PROBE" and turn on again; this time the trace will rise to whatever value of resistance the probe is. Each centimeter of height represents 2 volts or 25 ohms. The resistance wire used in the probes has a value of 86.6 ohms/ft, so a direct relationship of distance to time is established. The resistance of the completed probe plus small line losses is usually on the order of 95 - 105 ohms. After this value is determined, turn the constant-current box off and enter the appropriate readings on the check-off sheet. Be sure the box is turned OFF until just before the event because current drain on the battery is very heavy and the transistor will also get very hot and may burn up if left on for any extended length of time.

20. Now cap up the device, and ARM the firing circuit. Refer to Figure C-13 for the cap and explosive configuration.

21. Next, dial in the appropriate amount of delay on the Flash X-Ray delayed trigger amplifier. (See Figure C-5). Usually this will be in the order of 100 - 120 μsec, again depending on the detonation velocity. This must always be set to fire after both stress peaks have been recorded or its interference may destroy either pulse. For a detonation velocity of 3000 m/sec, an X-Ray setting of about 105 μsec would probably be adequate. Now check to see that gas pressures are correct:

FREON = 19 lb

NITROGEN = 25 lb

FREON (TUBEHEAD) 18 - 20 ounces

Make sure the high-voltage and ready lamps are lighted. Turn the high voltage key switch to "ON", and depress the "HIGH VOLTAGE ON" button. The red lamp should come on and one can now charge the system SLOWLY (Use no more than 1/2 ma charging current) to whatever value gives good X-Ray resolution. 23 KV appears to be entirely adequate. When the system is charged check the following items:

a. All three scope reset lamps lighted.

b. All three scope viewing ports shut.

c. Optionally, before the Flash X-Ray System is charged up.

Scopes #1 and #2 can be pre-baselined. This is accomplished by opening the shutters on cameras #1 and #2, operating the trigger box and then closing shutters #1 and #2. This provides a baseline reference against which the actual test baseline can be measured. This measure precludes or minimizes the possibility of drift, especially of the top trace (which is sensitive to temperature variations, etc.).

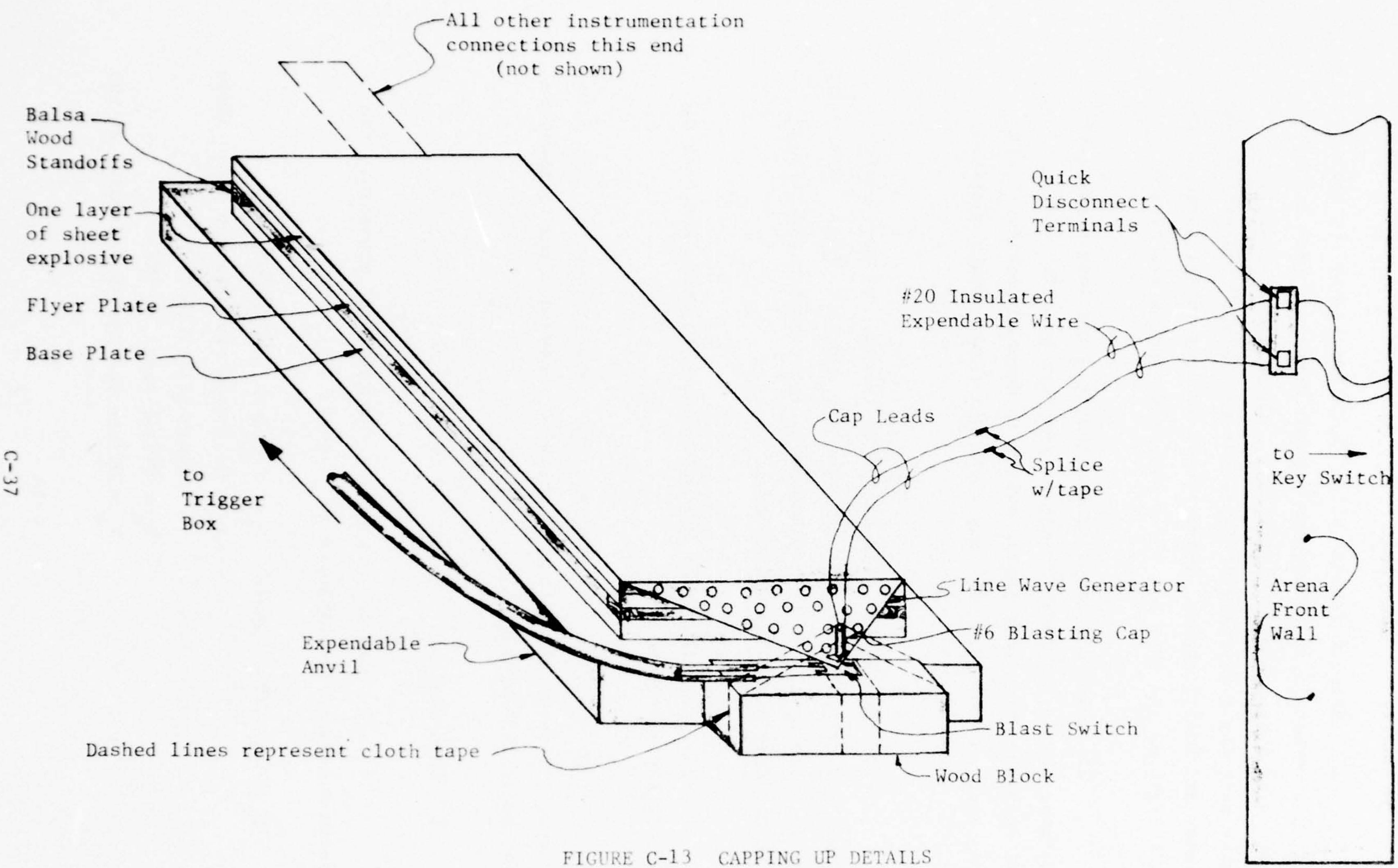


FIGURE C-13 CAPPING UP DETAILS

22. Connect firing switch (w/battery) assy. to firing circuit terminals in detonation control breaker. (Run through window of instrumentation facility). Chcek again visually to make sure the X-Ray trigger Amplifier red "READY" and yellow "HV" lamps are both lighted. Insure reset buttons on all three scopes are lighted, and that all three camera viewports are closed.

23. Open all three camera shutters and insure constant current box is in "PROBE" position and turn box "ON". Give warning on speaker. Now press firing switch to detonate device. Turn constant current box "OFF" and close all three camera shutters.

24. Operate the red button on the back of each camera; grasp end of paper and pull straight out until it stops. Now count to 15, then open the door on the back of the camera and retrieve photo. Coat with fixer provided.

25. Turn the X-Ray HV control down to zero, and turn the safety key switch to off.

26. Retrieve the specimen and armored cassette. The film develops very nicely in one of the 90 - second developing machines for medical X-Ray use.

D. Data Analysis

1. For both the detonation and interface pressures, the formula to find the pressure in kilobars is

$$P_k = \frac{V_p - V_b}{V_{c/3}}$$

where: P_k = Pressure, in Kilobars
V_p = Height of the pressure pulse above the baseline (MV)
V_b = Offset baseline (MV).
V_c = Offset voltage as indicated on the

Comparison Voltage Dial (V_c) on the "W" Plug in (VOLTS).

If the pressure in P.S.I. is desired, multiply this result by 14.7.

2. For the detonation velocity, draw a straight line to best coincide with the slope of the detonation velocity photo. (See Figure C-14). Since the vertical scale = 25 ohms per cm, and the known resistance of the probe is 86.6 ohms/ft the velocity is equal to $\frac{R}{86.6}/T$, where R is in ohms and T is in μsec and V_d is in ft/μsec. Of course, to express the result in m/s, as has usually been the case, multiply the result by $\left\{\frac{10^6}{3.28}\right\}$

3. A complete record of all Site experiments has been kept in three log books. One, the Master Log, contains a record of all tests. The instrumented shots that have been evaluated with a computer are located in another log, and all other tests are in the third log book. Additionally, a work sheet has been kept for each test. Use of these sheets, especially with the fully instrumented tests, tend to preclude operator error due to the relative complexity of the system.

E. Additional Information

1. The velocity probes are made from aluminum tubing and "skip" wound nylon insulated resistance wire with a resistance of 86.6 ohms/ft. The tubing has an inside diameter of about 19 mils with a wall thickness of 1 mil and is accordingly very fragile. The tube is measured (usually, one ft lengths have been used) scored with a sharp razor blade and broken off. By cutting the wire with very sharp side cutters or scissors it can be readily threaded through the tubing. One end is then pinched shut and a drop of "DUCO" cement or equivalent is applied to the other end. A small copper strip, with two or three inches of insulated wire

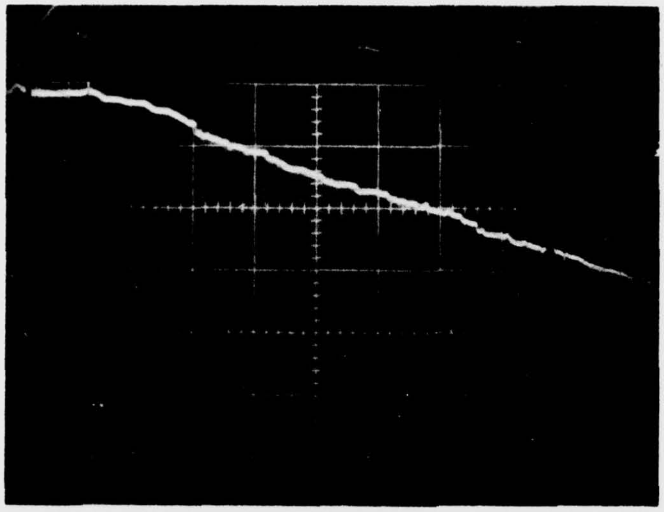
soldered to it, is placed over the probe at the connection end and taped down on both sides, so as to make good electrical connection, *but not with enough pressure to collapse the tube wall.* See Figure C-15 for completed probe. More information on this subject is contained in Document #R-7011-2157, (EIW DEVELOPMENT PROGRAM PROGRESS REPORT, Third Progress Review Meeting, dated 10/29/71.

2. Since the velocity probe is so fragile, great care must be taken when gluing it down to the specimen (using the same "DUCO" cement or equiv.) and when attaching the coax cable when the specimen is in position on the anvil. Once it is in place, remove the COAX fitting at the constant-current box marked "PROBE" , and measure with the VOM. The reading should be somewhere in the vicinity of 95 - 105. If markedly different from these values, the probe is either shorted or open, and appropriate repair is necessary.

3. *Before closing* the site for the day, it is highly advisable to completely shut off the Freon and Nitrogen bottles, because both systems have inherent small leaks that have been impossible to locate.

4. Before running a test it is advisable to take a test photograph with each of the three cameras (with the specimen completely wired), to insure proper operation of the cameras as well as all the systems involved. For the same reasons, it is advisable to "bleed" both gas systems of the X-Ray if it has been more than a few days since the last test. A dosimeter has been used to measure radiation onput from the X-Ray at various intervals, to insure proper operation. Electric blankets were placed over both pulsers (located in a shed next to the detonation arena) *to keep the Freon from* liquifying; the blanket must be temporarily removed from the pulser in operation before running the test or the high voltage pulse discharge will find a short-circuit across the blanket. Additionally, if there is ANY indication that

FIGURE C-14
OSCILLOSCOPE #3



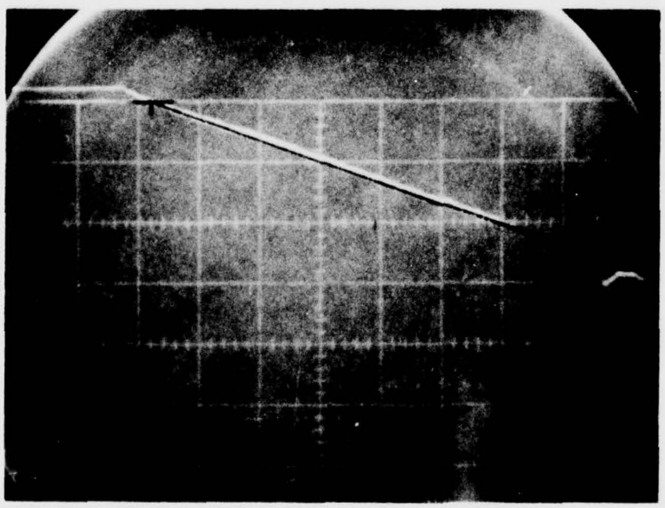
TOP TRACE ONLY

VERT = 2 V/cm
HORIZ = 10 μsec/cm

NO TIME DELAY

FIGURE C-14a - DETONATION VELOCITY TRACE
(WITH FULL INSTRUMENTATION)

$$V_o = \frac{R/86.6}{T} = \frac{75/86.6}{63} \times \frac{10^6}{3.28} = 4{,}180 \text{ M/sec}$$



TOP TRACE ONLY

VERT = 2 V/cm
HORIZ = 10 μsec/cm

NO TIME DELAY

FIGURE C-14b - DETONATION VELOCITY TRACE
(WITH FLASH X-RAY ONLY)

$$V_o = \frac{R/86.6}{T} = \frac{50/86.6}{56} \times \frac{10^6}{3.28} = 3{,}140 \text{ M/sec}$$

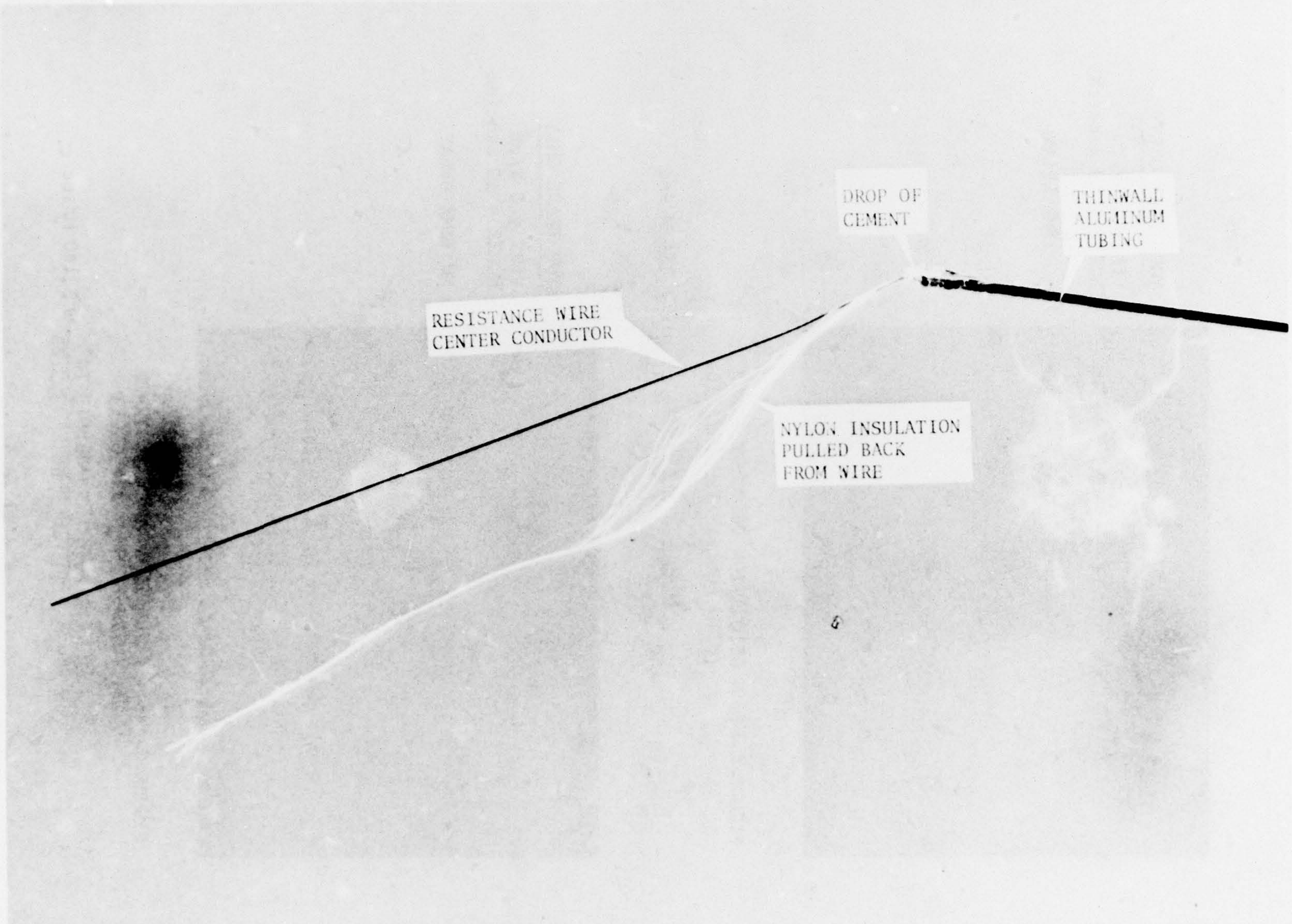


FIGURE C-15a
DETONATION VELOCITY PROBE

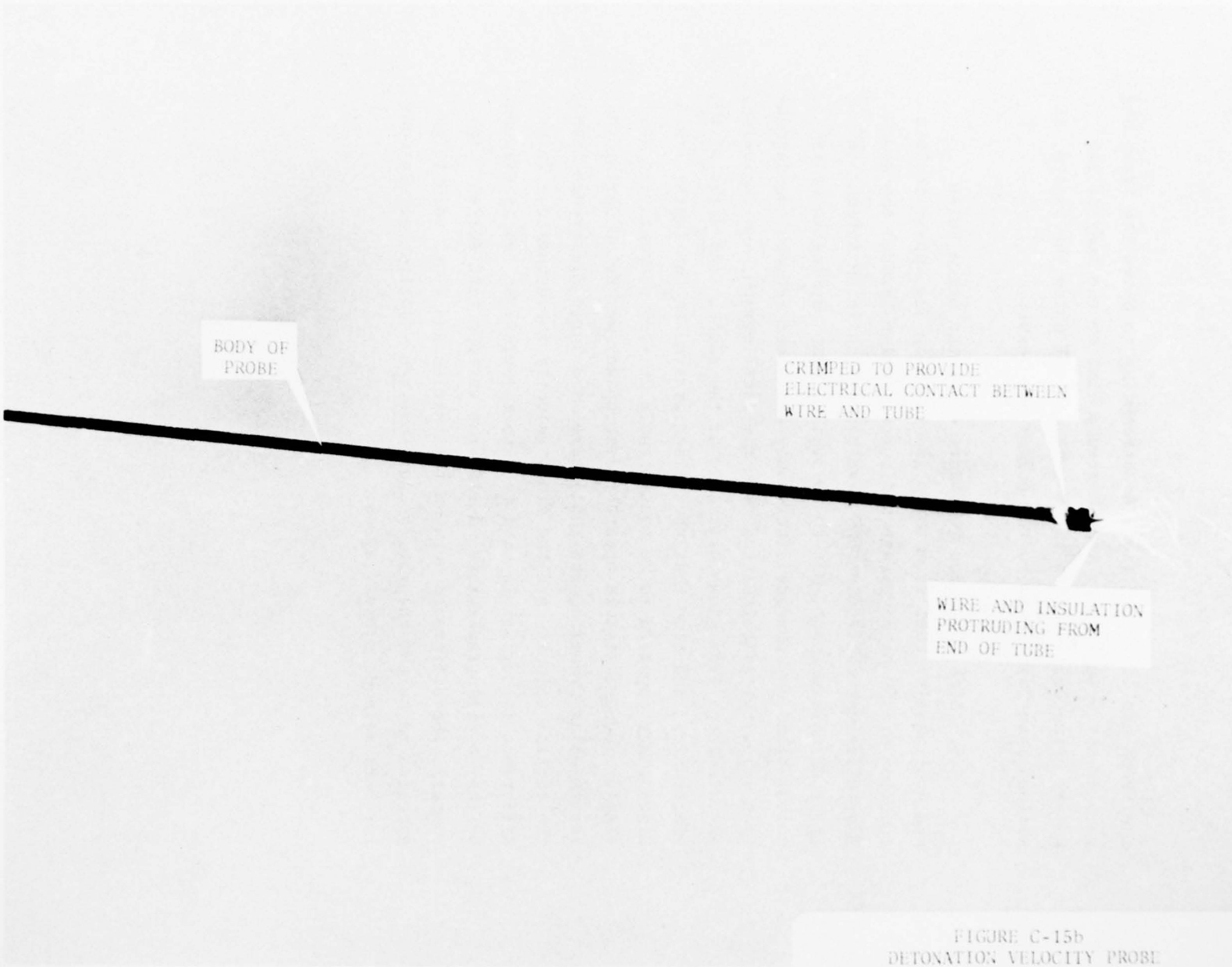


FIGURE C-15b
DETONATION VELOCITY PROBE

the Freon has liquefied (such as attempting to bleed the Freon and getting any result other than a steady hiss or the body of the pulser being very cold to the touch), do NOT pulse the system, or serious internal damage to the pulser may result.

5. With reference to Figure C-14, the extra noise and nonlinearity that seem to be generated in 13a appear to be a function of the high voltage and current pulse through the gages. Many different configuartions have been tried in an attempt to clear up this problem, but to no avail. Also, during velocity calculations an apparent discrepancy was noted between the detonation velocity, as calculated from the oscillograph, and the velocity as calculated from known distances of the gages, time delay of the electronics, and time that the pulses arrived at the gages. This discrepancy appeared to be consistently 20 - 25 percent. It was finally found that this apparent discrepancy was noted during the series using dynamite, and that there is a large difference between the initial velocity and the final velocity for dynamite. This difference is negligible with the sheet explosives, as is evidenced by many oscillographs taken during the various test series. In summary, the difference between the initial and final velocities appeared to be the culprit, because average velocity calculations for both methods closely agree.

APPENDIX D

CHARACTERISTICS OF EXPLOSIVES

During the months of October and November 1969 it was decided to repeat some explosion welding experiments from the parallel aluminum welding study to check repeatability. Forty percent extra dynamite from a different lot of explosive was used. Shear and tensile strength tests showed the weld strengths to be lower than for the original set of welds. Additional welding experiments indicated that the inferior results were attributable to the characteristics of the second lot of explosive. When the welding experiments were rerun with the original lot of explosive, the bond strengths were consistent with the original results. It was eventually determined that the second lot of explosive contained excessive moisture associated with the ammonium nitrate, an ingredient common to most medium and low detonation velocity dynamites.

These results cast considerable doubt about the suitability of granular, nitrate-containing dynamites either for explosion welding field applications, or for initiating other parametric investigations. An effort was begun to bring into the program another explosive with more favorable characteristics. IRECO Chemical Company of Salt Lake City, Utah, produces a series of slurry and gel explosives which appeared to be a reasonable basis for developing an explosion welding explosive. After some discussion, IRECO officials agreed to modify their slurry explosive and supply enough explosive to complete a series of preliminary welding experiments. The first

explosive composition supplied proved to have undesirable physical characteristics: viz, it was a putty-like composition, "sticky" and difficult to apply uniformly. A second explosive composition was supplied by IRECO, and on the strength of its welding performance was accepted, although the physical characteristics were not considered to be ideal. The second IRECO explosive was a water gel of proprietary composition. It had a physical consistency like "fresh liver". Its detonation velocity was 5000 m/sec at a density of 1.5 g/cm^3, and it had a relatively high impulse value. This explosive was purchased in sufficient quantity to conduct a steel-steel preset angle welding parametric study.

The IRECO gel explosive was supplied in cast 12 inch cubes. In order to cut sheets from these blocks as thin as 1/4 inch, it was necessary to develop a special cutting fixture. After evaluating several suggested methods, a "mitre box and meat saw" technique was adopted with successful results. A wooden mitre box with an internal sliding tray was built. The mitre box supported five sides of the explosive cube during cutting. The cutter was a stainless steel, serrated edge, meat-cutting band saw blade adapted to a stainless steel butcher's saw frame. If future applications and quantities warrant the expense, the explosive can be cast directly to sheet form.

Preliminary experiments indicated that the 5000 m/sec IRECO explosive was too powerful to use with aluminum plates less than 3/8 inch thick. Therefore, IRECO agreed to produce a lower density version of the 5000 m/sec explosive. The modified gel explosive

has a detonation velocity of 4000 m/sec, at a density of 1.2 g/cm^3, and a somewhat lower impulse value. During acceptance trials, the modified explosive proved to be suitable for the preset angle aluminum parametric study and was purchased in sufficient quantity to complete that task. It did not prove to be suitable, however, for the parallel plate geometry.

In an effort to meet the requirement for aluminum parallel plate welding, IRECO developed a third generation of gel explosive. This explosive was being field evaluated at the time but was introduced too late to be considered for use in the parallel steel plate study.

Both the high and low density IRECO explosives were found to possess some undesirable features. The tough water gel compositions lose their moisture during exposure to high temperatures (>90°F) and low humidity conditions. Therefore, for prolonged storage the IRECO explosives must be sealed in moisture-tight envelopes. In addition, the explosive is corrosive to both steel and aluminum and cannot remain in contact with either metal for an extended period without a corrosion-resistant intermediate barrier.

At about the time the IRECO explosives were proving to be somewhat unsuitable, it was learned that Thiokol Chemical Company had developed an experimental medium detonation velocity sheet explosive. Discussions with Thiokol and a visit to their plant at Brigham City, Utah, to evaluate some explosive samples clearly indicated the suitability of the explosive for welding. It was demonstrated that Thiokol can produce flexible, rubber-like explosive compositions in sheet form, having detonation velocities ranging from 3800 m/sec to

5000 m/sec. Thiokol provided, at no cost, 80 pounds of the 3800 m/sec sheet explosive for parallel steel-steel parametric welds. The explosive sheets are easily cut to the desired size with a knife. Moreover, the explosive is stable, waterproof, flexible and not corrosive on contact to steel or aluminum.

Eighteen steel to steel welds were made using 1/4 x 5 x 9 inch specimens, the parallel welding configuration and the experimental Thiokol explosive. The welding characteristics of the explosive were very good, and because of the ease of handling, welding set-up time was considerably shortened.

An additional 370 pounds of explosive was required to complete the parallel steel-steel parametric investigation. However, Thiokol priced the additional explosive at approximately $30/lb, a price far in excess of the funding limitations of the program. The Thiokol explosive, therefore, had to be dropped from consideration.

By replacing the binder agent in their sheet explosive with a less expensive material, Thiokol eventually was able to reduce the price of the explosive to approximately $10/lb in small quantities and to reduce significantly the delivery time. Under such circumstances, use of the Thiokol sheet explosive in parallel stand-off steel-steel welding appears attractive. The modified Thiokol sheet explosive reportedly has a detonation velocity of approximately 4100 m/sec and a density of 1.5 g/cc.

The Thiokol explosive is potentially the most suitable, if not the only low velocity sheet explosive ever developed especially for explosion welding. If the explosive achieves its potential and

the cost factors are favorable, the Thiokol compositions could make explosive impulse welding more generally competitive for field joining of special configurations. Thiokol has estimated a price of from \$2 to \$5 per pound when quantities in excess of 2000 lbs are required. Continued development of explosives should be encouraged.

While proof testing of the new Thiokol and IRECO explosives continued, a granular explosive composition produced by the Trojan Powder Company was selected for use in the parallel steel-steel welding study. The Trojan explosive, designated SWP-5, has a detonation velocity of approximately 3600 m/sec at a density of 1.0 g/cc and a relatively high impulse value. Eighteen steel to steel welds using 1/4 x 5 x 9 inch specimens were made using the parallel configuration to prove the welding characteristics of the Trojan explosive. SWP-5 is essentially 80/20 Amatol (ammonium nitrate/TNT) made in such a way that the TNT coats the ammonium nitrate, thus giving some protection against moisture pick-up by the ammonium nitrate. As delivered, the explosive is dry, free-flowing, and has good packing characteristics. At a cost of \$1/lb the explosive should find continued use for many shop welding applications requiring large amounts of explosive. However, for field applications where control over storage and handling over extended periods of time can be expected to increase the moisture content and related problems, the explosive is less desirable than the sheet being developed by Thiokol.

Table D-1. Characteristics of Explosives

Explosive	Type	Detonation Velocity, m/sec	Density, g/cm^3	Remarks
du Pont 40% Extra Dynamite	Moist, granular	3,300	1.25	Nitroglycerine sensitized; poor moisture resistance; variable quality; low impulse; must be packaged
IRECO Gel Low Density	Moist, tough foamed gel	4,000	1.2	Corrosive to aluminum and steel; medium impulse; must be packaged
IRECO Gel High Density	Moist, tough foamed gel	5,000	1.5	Corrosive to aluminum and steel; high impulse; must be packaged
Trojan Powder 80/20 Amatol SWP-5	Dry powder	3,600	1.0	Free-flowing when dry; some resistance to moisture pick-up; must be packaged; Medium I
Thiokol No. 1	Sheet	3,800	1.0	Porous sheet; poor flexibility; moisture-resistant; no packaging required
Thiokol No. 2	Sheet	4,200	1.4	Porous sheet; flexible; moisture-resistant; no packaging required
du Pont Detasheet C	Rubber sheet	6,900	1.4	Dense sheet

APPENDIX E

WELD2 COMPUTER PROGRAM

```
      PROGRAM WELD2 (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE1,TAPE2,
     1    TAPE3,TAPE4,TAPE11,TAPE12,TAPE13,TAPE26,TAPE27,TAPE28,TAPE29)
C
C     FINITE ELEMENT DYNAMIC INELASTIC AXISYMMETRIC CODE
C     FOR EXPLOSIVE IMPULSE WELDING ANALYSIS
C
      COMMON HED(12),IFLAG,NUMNP,NUMEL,NUMMAT,NEQB,MBAND,NNN,NT,TT,DELT,
     1 NPRINT,NP,NUMPC,NST,RA,ALFA,BETA,INTSEC,MAXSEC,NTSTOP,MTSTOP,IIK,
     2 M1,M2,M3,MN,ME,LA,IN,IO,LUN1,LUN2,LUN3,LUN4,LUN5,LUN6,LUN7,NTAPE,
     3 MAG,MAGOLD,LUN8,KOM
      DIMENSION AJA(9),A(40000)
      DATA (AJA(I),I=1,9)/6HA G B ,6HA B I ,6HA N - ,6HJ A C ,6HO B S ,
     16HE N  A,6H S S O,6H C I A,6H T E S/
      DATA TSTART,IBAIL,IKLOK/6HSTART ,0,0/
C
      CALL KLOK (IKLOK,0,0,IBAIL,SEC,ISEC)
C      -- IF DIMENSION OF A IN COMMON IS CHANGED,
C           FOLLOWING SETTING OF KOMMON MUST ALSO BE CHANGED --
      KOMMON=40000
      DO 1 I=1,KOMMON
      A(I)=0.0
    1 CONTINUE
      LCOM=40
      NNNO=0
      IN=5
      IO=6
C
      READ(IN,1003) LUN1,LUN2,LUN3,LUN4,LUN5,LUN6,LUN7,LUN8,NTAPE,
     .  MAG,MAGOLD,NWORD
      READ (IN,1001) RUN,IREST,IMAG
      IF (RUN.EQ.TSTART) GO TO 50
      IF (IMAG.NE.0) MAG=MAGOLD
      REWIND MAGOLD
      IBAIL=3
      READ (MAGOLD) LCOM,(HED(I),I=1,LCOM)
      NNNO=NNN
      REWIND NTAPE
      GO TO 70
C--------
C     READ AND PRINT OF CONTROL INFORMATION
C-------
   50 IF (IREST.EQ.0) GO TO 60
      READ (IN,1002) INTSEC,MAXSEC,NTSTOP
      IF (IMAG.NE.0) MAGOLD=MAG
   60 READ (IN,1000) (HED(I),I=1,12),
     .    NUMNP,NUMEL,NUMMAT,NT,NPRINT,NP,NUMPC,NST,ALFA,BETA,DELT,RA
      REWIND NTAPE
      WRITE(NTAPE)(AJA(I),I=1,9),(HED(I),I=1,12),
     .    NUMNP,NUMEL,NUMMAT,NT,NPRINT,NP,NUMPC,NST,ALFA,BETA,DELT,RA
      IF(NWORD.EQ.0) GO TO 62
      NDATA=33+67*NUMMAT+5*NUMEL+7*NUMPC+2*NP+9* NUMNP
      NTEST=(NWORD*1000-NDATA)/(8*NUMEL+8*NUMNP)-1
      IF(NTSTOP.LE.NTEST.AND.NT.LE.NTEST) GO TO 62
      WRITE(IO,1004) NTSTOP,NTEST
      NTSTOP=NTEST
   62 CONTINUE
      MTSTOP=NTSTOP
C-------
```

```
C       READ AND PRINT OF DATA
C-------
        IFLAG=1
   70   N2=1+7*NUMMAT
        N3=N2+60*NUMMAT
        N4=N3+NUMPC
        N5=N4+NUMPC
        N6=N5+NUMPC
        N7=N6+NUMPC
        N8=N7+NUMPC
        N9=N8+NUMPC
        N10=N9+NUMPC
        N11=N10+2*NP
        N11M1=N11-1
        KOM=(KOMMON-N11+1)/2
        IF (IBAIL.EQ.3) GO TO 75
        M1=2*KOM/33
        M1=MIN0(M1,NUMNP)
        MN=11*M1
        M2=(KOM-MN)/22
        M2=MIN0(M2,NUMEL)
        ME=22*M2
   75   N12=N11+M1
        N13=N12+M1
        N14=N13+M1
        N15=N14+2*M1
        N16=N15+2*M1
        N17=N16+2*M1
        N18=N17+2*M1
        N19=N18+5*M2
        N20=N19+10*M2
        N21=N20+5*M2
        N21A=N21+2*M2
        IF (IBAIL.EQ.3) GO TO 90
        IF(M1.LT.NUMNP.OR.M2.LT.NUMEL) IFLAG=2
        IF(M1.LT.NUMNP.OR.M2.LT.NUMEL) WRITE(IO,1005) MN,ME
        CALL DATAIN(A(1),A(N2),A(N3),A(N4),A(N5),A(N6),A(N7),A(N8),A(N9),
       1A(N10),A(N11),A(N12),A(N13),A(N14),A(N15),A(N16),A(N17),A(N18),
       2A(N18),A(N19),A(N20),A(N21),KOMMON)
C-------
   90   NEQ=2*NUMNP
        IF(IFLAG.EQ.2) GO TO 100
        IF (IBAIL.EQ.0) NEQB=NEQ
        N22=N21A+NEQ*MBAND
        N23=N22+NEQ
        N24=N23
        N25=N23
        N26=N23
        N27=N21A
        GO TO 200
  100   IF (IBAIL.EQ.0) NEQB=(KOMMON-N11+1)/(2*MBAND+4)
        IF(M1.GE.NUMNP.AND.M2.GE.NUMEL) WRITE(IO,1006) NEQB,MBAND
        N21A=N11
        N22=N11+KOM
        N23=N22+NEQ
        N24=N23+NUMNP
        IF (IBAIL.EQ.0) M3=(KOM-3*NUMNP)/72
        N25=N24+54*M3
```

```
      N26=N21A+NEQB*(MBAND+1)
      N27=N22
      NMAX=11*NST+NUMNP
      IF(NMAX.GT.KOM) CALL EXIT
      IF(M3.LT.1.OR.NEQB.LT.1) CALL EXIT
  200 CALL SOLVE(A(1),A(N2),A(N3),A(N4),A(N5),A(N6),A(N7),A(N8),A(N9),
     1A(N10),A(N11),A(N12),A(N13),A(N14),A(N15),A(N16),A(N17),A(N18),
     2A(N18),A(N19),A(N20),A(N21),A(N21A),A(N22),A(N23),A(N24),A(N25),
     3A(N26),A(N27),IBAIL,LCOM,N11M1,IREST,IKLOK)
C------------
C     PRINTOUT OF DATA AND RESULTS
C----------
      NTA=MNN-1-NNNO
      CALL OUTPUT(A(1),A(N2),A(N3),A(N4),A(N5),A(N6),A(N7),A(N8),A(N9),
     1A(N10),A(N11),A(N12),A(N13),A(N14),A(N15),A(N16),A(N17),A(N18),
     2A(N18),A(N19),A(N20),A(N21),NTA,NNNO,AJA)
C
 1000 FORMAT(12A6/8I5,4F10.0)
 1001 FORMAT (A6,2I1)
 1002 FORMAT (3I5)
 1003 FORMAT(12I5)
 1004 FORMAT(52H NTAPE HAS INSUFFICIENT LENGTH, RESTART CYCLE NUMBER,I5,
     .  9H RESET AT,I5)
 1005 FORMAT(40H NODAL POINT OR ELEMENT DATA OUT OF CORE/
     .  28H      NODAL DATA BLOCK LENGTH,I10,
     . /30H      ELEMENT DATA BLOCK LENGTH, I10)
 1006 FORMAT(17H USOL OUT OF CORE/,21H STIFFNESS BLOCK SIZE,I10,3H BY,
     .  I10)
C
      END
```

```
      SUBROUTINE COMPUT(COEFF,STRINC,STRESS,STRSIN)
      DIMENSION COEFF(4,4),STRINC(4),STRESS(4),STRSIN(4)
   35 DO 50 I=1,4
      DUM=0.
      DO 40 J=1,4
      DUM=COEFF(I,J)*STRINC(J)+DUM
   40 CONTINUE
      STRSIN(I)=DUM
   50 CONTINUE
C
      DO 60 I=1,4
      STRESS(I)=STRESS(I)+STRSIN(I)
   60 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CONECT(STRAIN,STRESS,PROP,COEFF,IX,N,DELT,
     .  NUMYLD,YLDDAT,NEL)
      DIMENSION STRAIN(10),STRESS(5),PROP(7),COEFF(60),IX(5),YLDDAT(2,1)
      COMMON/LS4ARG/LM(8),SS(4,8),XC,YC,S(8,8),C(4,4),DEPS(4)
      COMMON/ELPLS/BLK,SHR,C1,C2,C3,DUM,UMAX,PMAX,YCOF(20),BCOF(30),
     .SCOF(10),ELSTRN(4),STRINC(4)
C
C     PREPARE TO CALL ELPL
C
      DO 100 I=1,20
  100 YCOF(I)=COEFF(I)
      DO 101 I=1,30
  101 BCOF(I)=COEFF(I+20)
      DO 102 I=1,10
  102 SCOF(I)=COEFF(I+50)
      BLK=PROP(1)
      SHR=PROP(2)
      C1=PROP(5)
      C2=PROP(6)
      C3=PROP(7)
      DO 110 I=1,4
      STRINC(I)=DEPS(I)
  110 ELSTRN(I)=STRAIN(I+4)
C
C
      SIGNAL=0.
      DUM=ABS(STRAIN(9))
      UMAX=ABS(STRAIN(10))
      PMAX=STRESS(5)
      CALL ELPL(STRESS,STRAIN,C,SIGNAL,FACTOR,DELT,DEPS)
      IF(SIGNAL.LE.0.) GO TO 120
      NUMYLD=NUMYLD+1
      YLDDAT(1,NUMYLD)=NEL
      YLDDAT(2,NUMYLD)=FACTOR
  120 CONTINUE
      IF(DUM.GT.UMAX) STRAIN(10)=STRAIN(9)
      STRAIN(9)=(1.+ELSTRN(1)+ELSTRN(2)+ELSTRN(1)*ELSTRN(2)-.25*
     .ELSTRN(4)*ELSTRN(4))*(1.+ELSTRN(3))-1.
      STRESS(5)=PMAX
  150 CONTINUE
      DO 200 I=1,4
  200 STRAIN(I+4)=ELSTRN(I)
      RETURN
      END
```

```
      SUBROUTINE COORD(R,Z,CODE,X0,B,X1,X2,I,J,K,L,NCRNT,NLAST,M1,NNPT,
     1MM)
      DIMENSION R(1),Z(1),CODE(1),B(1),X0(1),X1(1),X2(1)
      COMMON/CORD/RI,RJ,RK,RL,ZI,ZJ,ZK,ZL,COD(4),DISP(8),VEL(8),ACCL(8)
      II=I
      JJ=J
      KK=K
      LL=L
   10 NMIN=NCRNT*M1-M1+1
      NMAX=M1*NCRNT
      IF(II.EQ.0) GO TO 20
      IF((I.LT.NMIN).OR.(I.GT.NMAX)) GO TO 20
      RI=R(I-NMIN+1)
      ZI=Z(I-NMIN+1)
      COD(1)=CODE(I-NMIN+1)
      NN=2*(I-NMIN+1)
      DISP(1)=X0(NN-1)
      DISP(2)=X0(NN)
      VEL(1)=X1(NN-1)
      VEL(2)=X1(NN)
      ACCL(1)=X2(NN-1)
      ACCL(2)=X2(NN)
      II=0
   20 IF(JJ.EQ.0) GO TO 30
      IF((J.LT.NMIN).OR.(J.GT.NMAX)) GO TO 30
      RJ=R(J-NMIN+1)
      ZJ=Z(J-NMIN+1)
      COD(2)=CODE(J-NMIN+1)
      NN=2*(J-NMIN+1)
      DISP(3)=X0(NN-1)
      DISP(4)=X0(NN)
      VEL(3)=X1(NN-1)
      VEL(4)=X1(NN)
      ACCL(3)=X2(NN-1)
      ACCL(4)=X2(NN)
      JJ=0
   30 IF(KK.EQ.0) GO TO 40
      IF((K.LT.NMIN).OR.(K.GT.NMAX)) GO TO 40
      RK=R(K-NMIN+1)
      ZK=Z(K-NMIN+1)
      COD(3)=CODE(K-NMIN+1)
      NN=2*(K-NMIN+1)
      DISP(5)=X0(NN-1)
      DISP(6)=X0(NN)
      VEL(5)=X1(NN-1)
      VEL(6)=X1(NN)
      ACCL(5)=X2(NN-1)
      ACCL(6)=X2(NN)
      KK=0
   40 IF(LL.EQ.0) GO TO 50
      IF((L.LT.NMIN).OR.(L.GT.NMAX)) GO TO 50
      RL=R(L-NMIN+1)
      ZL=Z(L-NMIN+1)
      COD(4)=CODE(L-NMIN+1)
      NN=2*(L-NMIN+1)
      DISP(7)=X0(NN-1)
      DISP(8)=X0(NN)
      VEL(7)=X1(NN-1)
```

```
      VEL(8)=X1(NN)
      ACCL(7)=X2(NN-1)
      ACCL(8)=X2(NN)
      LL=0
   50 NCHECK=II+JJ+KK+LL
      IF(NCHECK.EQ.0) RETURN
      IF(NCRNT.LT.NLAST) GO TO 60
      REWIND NNPT
      NCRNT=0
   60 NCRNT=NCRNT+1
      READ (NNPT)(R(III),III=1,MM)
      GO TO 10
      END
```

```
      SUBROUTINE DATAIN(PROP,COEFF,HI,HJ,VI,VJ,T,INI,JNJ,P,R,Z,CODE,F,
     .XO,X1,X2,IX,ED,EPS,SIG,YLDDAT,KOMMON)
C
      COMMON HED(12),IFLAG,NUMNP,NUMEL,NUMMAT,NEQB,MBAND,NNN,NT,TT,DELT,
     1 NPRINT,NP,NUMPC,NST,RA,ALFA,BETA,INTSEC,MAXSEC,NTSTOP,MTSTOP,IIK,
     2 M1,M2,M3,MN,ME,LA,IN,IO,LUN1,LUN2,LUN3,LUN4,LUN5,LUN6,LUN7,NTAPE,
     3 MAG,MAGOLD,LUN8,KOM
      DIMENSION PROP(7,1),COEFF(60,1),HI(1),HJ(1),VI(1),VJ(1),T(1),
     .INI(1),JNJ(1),P(2,1),R(1),Z(1),CODE(1),F(1),XO(1),X1(1),X2(1),
     .IX(5,1),EPS(10,1),SIG(5,1),YLDDAT(2,1),ED(1),IXM(10),IXN(5)
      IF(IFLAG.EQ.1) GO TO 10
      REWIND LUN2
      REWIND LUN3
   10 CONTINUE
C
C--------
C     READ AND PRINT OF MATERIAL PROPERTIES
C-------
      DO 50 M=1,NUMMAT
      READ (5,1001) MTYPE,(PROP(I,MTYPE),I=1,7)
      IF(PROP(5,MTYPE).GT.0.) READ(5,1005) (COEFF(I,MTYPE),I=1,20)
      IF(PROP(6,MTYPE).GT.0.) READ(5,1005) (COEFF(I,MTYPE),I=21,50)
      IF(PROP(7,MTYPE).GT.0.) READ(5,1005) (COEFF(I,MTYPE),I=51,60)
   50 CONTINUE
      WRITE (NTAPE) ((PROP(I,M),I=1,7),M=1,NUMMAT),((COEFF(I,M),I=1,60)
     1,M=1,NUMMAT)
C--------
C     READ AND PRINT OF NODAL POINT DATA
C--------
      L=0
      NROW=0
   60 READ(5,1002) N,CODEN,RN,ZN,XORN,XOZN,X1RN,X1ZN
      RN=RN+RA
      IF(L.EQ.0)GO TO 85
      ZX=N-L
      DR=(RN-RL)/ZX
      DZ=(ZN-ZL)/ZX
   85 NL=L+1
   70 L=L+1
      IF(N-L)100,90,80
   80 CODEL=0.
      RL=RL+DR
      ZL=ZL+DZ
      XORL=0.
      XOZL=0.
      X1RL=0.
      X1ZL=0.
      GO TO 91
   90 RL=RN
      ZL=ZN
      CODEL=CODEN
      XORL=XORN
      XOZL=XOZN
      X1RL=X1RN
      X1ZL=X1ZN
   91 NROW=NROW+1
      NN=NN+1
      R(NROW)=RL
```

```
      Z(NROW)=ZL
      CODE(NROW)=CODEL
      XO(2*NROW-1)=XORL
      XO(2*NROW)=XOZL
      X1(2*NROW-1)=X1RL
      X1(2*NROW)=X1ZL
      IF(NROW.EQ.M1) GO TO 92
      IF(L.LT.N) GO TO 70
      IF(NUMNP-N) 100,92,60
  100 WRITE (6,2009) N
      CALL EXIT
   92 IF(IFLAG.EQ.1) GO TO 110
      WRITE(LUN2)(R(I),I=1,MN)
      NROW=0
      IF(L.LT.N) GO TO 70
      IF(NUMNP-N)100,120,60
  110 CONTINUE
  120 CONTINUE
C--------
C     READ AND PRINT OF ELEMENT NODES
C--------
      N=0
      MBAND=0
      NROW=0
  130 READ(5,1003) M,(IXM(I),I=1,10)
      MB=0
C
C     DETERMINE BANDWIDTH
C
      IF(IXM(6).NE.0) GO TO 135
      DO 160 I=1,4
      DO 160 J=1,4
      MM=IABS(IXM(I)-IXM(J))
      IF(MM.GT.MB)MB=MM
  160 CONTINUE
      GO TO 137
  135 DO 133 I=1,10
      IF((I.EQ.5).OR.(I.EQ.6))GO TO 133
      DO 132 J=I,10
      IF((J.EQ.5).OR.(J.EQ.6)) GO TO 132
      MM=IABS(IXM(I)-IXM(J))
      IF(MM.GT.MB)MB=MM
  132 CONTINUE
  133 CONTINUE
  137 MB=2*MB+2
      IF(MB.GT.MBAND) MBAND=MB
  140 N=N+1
      IF(M.EQ.N) GO TO 145
      DO 142 I=1,4
  142 IXN(I)=IXN(I)+1
      GO TO 149
  145 DO 148 I=1,5
  148 IXN(I)=IXM(I)
  149 CONTINUE
      NROW=NROW+1
      DO 152 I=1,5
  152 IX(I,NROW)=IXN(I)
      IF(NROW.EQ.M2) GO TO 155
```

```
      IF(N.EQ.NUMEL) GO TO 700
      IF(N.EQ.M) GO TO 130
      GO TO 140
  155 IF(IFLAG.EQ.1) GO TO 700
      WRITE(LUN3)(ED(I),I=1,ME)
      WRITE(NTAPE)((IX(J,K),J=1,5),K=1,M2)
      NROW=0
      IF (N.EQ.NUMEL) GO TO 705
      IF(N.EQ.M) GO TO 130
      GO TO 140
  700 CONTINUE
      IF(IFLAG.NE.1) WRITE (LUN3) (ED(I),I=1,ME)
      WRITE(NTAPE)((IX(J,K),J=1,5),K=1,M2)
C---- --
C     PRESSURE BOUNDARY CONDITIONS
C---- --
  705 IF (NUMPC.EQ.0) GO TO 400
      DO 330 K=1,NUMPC
      READ (5,1007) INI(K),JNJ(K),A,B,T(K),RI,RJ,ZI,ZJ
      I=INI(K)
      J=JNJ (K)
      DZ=(ZI-ZJ)/12.0
      DR=(RJ-RI)/12.0
      RX=A*(7.0*RI+RJ)+B*(RI+RJ)
      ZX=A*(RI+RJ)+B*(RI+3.0*RJ)
      HI(K)=RX*DZ
      HJ(K)=ZX*DZ
      VI(K)=RX*DR
      VJ(K)=ZX*DR
  330 CONTINUE
      WRITE (NTAPE)(HI(K),VI(K),HJ(K),VJ(K),T(K),INI(K),JNJ(K),
     1K=1,NUMPC)
C---- --
C      READ AND PRINT OF LOAD DATA
C---- ---
      DO 380 M=1,NP
  380 READ(5,1004) (P(K,M),K=1,2)
      WRITE  (NTAPE)  ((P(K,M),K=1,2),M=1,NP)
C---- ---
  400 CONTINUE
      IF(IFLAG.EQ.2)RETURN
      NCK=67*NUMMAT+14*NUMNP+22*NUMEL+2*NP+7*NUMPC+2*NUMNP*MBAND
      IF(NCK.LE.KOMMON) RETURN
      IFLAG=2
      REWIND LUN2
      REWIND LUN3
      WRITE(LUN2)(R(I),I=1,MN)
      WRITE(LUN3)(ED(I),I=1,ME)
C---------
      RETURN
 1001 FORMAT(I5,4F15.0,3F5.0)
 1002 FORMAT (I5,F5.1,6F10.0)
 1003 FORMAT (11I5)
 1004 FORMAT (2F10.0)
 1005 FORMAT(10F8.0)
 1007 FORMAT (2I5,7F10.0)
 2009 FORMAT (26HONDAL POINT CARD ERROR N= I5)
      END
```

```
      SUBROUTINE ELAST(B,G,C)
      DIMENSION C(4,4)
      C(1,1) = B +1.333*G
      C(1,2) = B-.6667*G
      C(4,4)=G
C
      C(1,3)=C(1,2)
      C(1,4)=0.
      C(2,1)=C(1,2)
      C(2,2) =C(1,1)
      C(2,3)=C(1,2)
      C(2,4)=0.
      C(3,1)=C(1,2)
      C(3,2)=C(1,2)
      C(3,3)=C(1,1)
      C(3,4)=0.
      C(4,1)=0.
      C(4,2)     =0.
      C(4,3)=0.
      RETURN
      END
```

```
      SUBROUTINE ELFUN(STRESS,STRAIN)
      DIMENSION STRESS(1),STRAIN(1)
      COMMON/ELPLS/B,G,C1,C2,C3,DUM,UMAX,PMAX,YCOF(20),BCOF(30),
     .SCOF(10),ELSTRN(4),STRINC(4)
      IF(C2.LE.0.) GO TO 100
C VARIABLE  BULK  MODULUS
      E1=ELSTRN(1)
      E2=ELSTRN(2)
      E3=ELSTRN(3)
      E4=ELSTRN(4)
      UCRNT=ABS((1.+E1+E2+E1*E2-.25*E4*E4)*(1.+E3)-1.)
      B=BCOF(1)+2.*BCOF(2)*UCRNT+3.*BCOF(3)*UCRNT*UCRNT
  100 IF(C3.LE.0.) RETURN
C VARIABLE SHEAR  MODULUS
      DUM2=STRESS(1)+STRESS(2)+STRESS(3)
      IF(DUM2.LE.PMAX) GO TO 200
C UNLOADING/RELOADING
      G=SCOF(5)+DUM2*SCOF(6)
      IF(G.GT.SCOF(7))G=SCOF(7)
      RETURN
C VIRGIN LOADING
C     INITIAL G (FUNCTION OF J1)
  200 G=SCOF(1)+SCOF(2)*DUM2/(DUM2+SCOF(3))
      PMAX=DUM2
      IF(C1.LE.0.) RETURN
C     G AS A FUNCTION OF SQRT(J2)
      DUM1=.1667*((STRESS(1)-STRESS(2))**2+(STRESS(2)-STRESS(3))**2+
     1(STRESS(3)-STRESS(1))**2)+STRESS(4)**2
      DUM1=SQRT(DUM1)
      IF(DUM2.LT.YCOF(5)) GO TO 210
      ALPHA=YCOF(1)
      CEE=YCOF(2)
      GO TO 220
  210 ALPHA=YCOF(3)
      CEE=YCOF(4)
  220 G=G*(1.-.98*DUM1/(ALPHA*DUM2+CEE))**SCOF(4)
      RETURN
      END
```

```
      SUBROUTINE ELPL(STRESS,STRAIN,COEFF,SIGNAL,FACTOR,DELT,DEPS)
      DIMENSION STRESS(1),STRAIN(1),COEFF(4,1),DEPS(1),STRSIN(4)
      COMMON/ELPLS/B,G,C1,C2,C3,DUM,UMAX,PMAX,YCOF(20),BCOF(30),
     .SCOF(10),ELSTRN(4),STRINC(4)
      DIMENSION STROLD(4)
      DO 5 I=1,4
    5 STROLD(I)=STRESS(I)
      IREG=1
      IF(C2.LE.0..AND.C3.LE.0.) GO TO 10
      CALL ELFUN(STRESS,STRAIN)
   10 CONTINUE
      CALL ELAST(B,G,COEFF(1,1))
      CALL COMPUT(COEFF(1,1),STRINC(1),STRESS(1),STRSIN(1))
      IF(C1.LE.0.) GO TO 30
      CALL TSTYLD(IREG,STRESS,1,ALPHA,CEE,YCOF,FACTOR)
      IF(IREG.EQ.1) GO TO 30
      SIGNAL=1.
      INELAS=C1
      GAMMA=YCOF(20)
      IF(INELAS.EQ.3)
     .  CALL VPLAST(STRESS(1),ALPHA,CEE,GAMMA,G,FACTOR,DELT)
      IF(INELAS.EQ.3) GO TO 30
      IF(INELAS.EQ.2)
     .  CALL NPLAST(STRESS(1),DEPS(1),B,G,ALPHA)
      IF(INELAS.EQ.2) GO TO 25
      DO 20 I=1,4
      STRESS(I)=STRESS(I)-STRSIN(I)
   20 CONTINUE
      CALL YLDFUN(STRESS(1),COEFF(1,1),B,G,ALPHA,CEE,IREG)
      CALL COMPUT(COEFF(1,1),STRINC(1),STRESS(1),STRSIN(1))
C     THIS CALL TO TSTYLD ADJUSTS THE DEVIATORS SO THAT STRESS EXACTLY
C     SATISFIES THE YIELD CONDITION
C
      SIGNAL=1.
   25 CALL TSTYLD(IREG,STRESS,2,ALPHA,CEE,YCOF,FACTOR)
      IF(IREG.EQ.1)CALL ELAST(B,G,COEFF(1,1))
   30 DO 40 I=1,4
   40 STRSIN(I)=STRESS(I)-STROLD(I)
      DP=.333333*(STRSIN(1)+STRSIN(2)+STRSIN(3))
      DO 50 I=1,3
   50 ELSTRN(I)=ELSTRN(I)+DP/(3.*B)+.5*(STRSIN(I)-DP)/G
      ELSTRN(4)=ELSTRN(4)+STRSIN(4)/G
      RETURN
      END
```

```
      SUBROUTINE FORMK (MAX,MIN,KSHIFT,A,NRA,EK,LM,INCORE,COPL2,MBAND,
     1 ND,NE,NEB)
C
      LOGICAL INCORE,COPL2
      DIMENSION A(NRA,1),EK(8,1),LM(1)
C
      IF (INCORE) GO TO 140
      IC=0
      IL=0
  100 IL=IL+1
      IF (IL.GT.8) GO TO 260
      N=LM(IL)
      IF (N.LE.0) GO TO 100
      IF ((N.GE.MIN).AND.(N.LE.MAX)) GO TO 120
      IC=IC+1
      GO TO 100
C
  120 IF (COPL2) GO TO 140
      I=IL
      GO TO 180
C
  140 I=0
  160 I=I+1
  180 IG=LM(I)-KSHIFT
      DO 220 J=1,8
      LMA=LM(J)
      IF (LMA.LT.0) LMA=-LMA
      JG=LMA-IG+1-KSHIFT
      IF (JG.LT.1) GO TO 220
      IF (JG.LE.MBAND) GO TO 200
      N=(ND-1)*NEB+NE
      WRITE (6,2000) N
      CALL EXIT
  200 A(IG,JG)=A(IG,JG)+EK(I,J)
  220 CONTINUE
      IF (INCORE) GO TO 240
      IF (COPL2) GO TO 240
      LM(IL)=-LM(IL)
      GO TO 100
C
  240 IF (I.LT.8) GO TO 160
      GO TO 280
C
  260 IF (IC.GT.0) RETURN
  280 EK(1,1)=-1.0
C
      RETURN
C
 2000 FORMAT (29H0A COEFFICIENT OF ELEMENT NO.,I5,18H GOES OUT OF BAND.)
C
      END
```

```
      SUBROUTINE GMASS (IX,MASS,AC,RO,XC,VOL)
      REAL MASS
      DIMENSION IX(5),MASS(1),ELMASS(4)
      COMMON/CORD/R(4),Z(4),COU(4),DISP(8),VEL(8),ACCEL(8)
      I=1
      J=2
      K=3
      L=4
      IF(IX(2).NE.IX(3)) GO TO 10
      RRR=VOL*RO*.25
      ELMASS(1)=RRR
      ELMASS(2)=RRR
      ELMASS(3)=RRR
      ELMASS(4)=RRR
      GO TO 20
   10 RM=8.*XC
      ROM=RO/72.
      R12=R(I)-R(J)
      R13= R(I)-R(K)
      R14=R(I)-R(L)
      R23=R(J)-R(K)
      R24=R(J)-R(L)
      R34=R(K)-R(L)
      Z12=Z(I)-Z(J)
      Z13=Z(I)-Z(K)
      Z14=Z(I)-Z(L)
      Z23=Z(J)-Z(K)
      Z24 =Z(J)-Z(L)
      Z34=Z(K)-Z(L)
      BR=(R34*Z12-Z34*R12)*ROM
      AR=(VOL+VOL)/XC *ROM
      CR=(R23*Z14-Z23*R14)*ROM
      ELMASS(1)=AR*(RM+R13+R(I))-BR*(R(I)+R(I)+R(L))+CR*(R(I)+R(I)+R(J))
      ELMASS(2)=AR*(RM+R24+R(J))+BR*(R(J)+R(J)+R(K))-CR*(R(I)+R(J)+R(J))
      ELMASS(3)=AR*(RM+R(K)-R13)+BR*(R(J)+R(K)+R(K))-CR*(R(K)+R(K)+R(L))
      ELMASS(4)=AR*(RM+R(L)-R24)-BR*(R(I)+R(L)+R(L))+CR*(R(K)+R(L)+R(L))
   20 DO 30 I=1,4
      II=IX(I)
      MASS(II)=MASS(II)+AC*ELMASS(I)
   30 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE GSTIFF (ITAPE,ITAPES,JTAPE,KTAPE,NEQB,MBAND,NBK,NUMEL,
     1 NEB,NDB,A,NRA,EK,EKC,LM,LMC,MASS)
C
      REAL MASS
      LOGICAL INCORE,COPL2
      DIMENSION A(NRA,1),EK(64,1),EKC(1),LM(8,1),LMC(1),MASS(1)
C
      INCORE=NBK.EQ.1
      COPL2=.FALSE.
      LEK=64*NEB
      LLM=8*NEB
      IT=ITAPE
      REWIND IT
      DO 100 I=1,NRA
      DO 100 J=1,MBAND
      A(I,J)=0.0
  100 CONTINUE
C
      IF (INCORE) GO TO 120
      JT=JTAPE
      REWIND JT
      REWIND KTAPE
      NBLK=0
      MAX=0
      KSHIFT=-NEQB
      GO TO 140
C
  120 KSHIFT=0
      GO TO 160
C
  140 NBLK=NBLK+1
      MIN=MAX+1
      MAX=MIN+NEQB-1
      KSHIFT=KSHIFT+NEQB
C
  160 NEL=NEB
      NELL=NUMEL+NEB
      DO 220 ND=1,NDB
      READ (IT) (EKC(I),I=1,LEK),(LMC(I),I=1,LLM)
      NELL=NELL-NEB
      IF (NELL.LT.NEB) NEL=NELL
      DO 200 NE=1,NEL
      IF (INCORE) GO TO 180
      IF (EK(1,NE).LT.0.) GO TO 200
  180 CALL FORMK (MAX,MIN,KSHIFT,A,NRA,EK(1,NE),LM(1,NE),INCORE,COPL2,
     1 MBAND,ND,NE,NEB)
  200 CONTINUE
      IF (INCORE) GO TO 220
      IF (NBLK.EQ.NBK) GO TO 220
      WRITE (JT) (EKC(I),I=1,LEK),(LMC(I),I=1,LLM)
  220 CONTINUE
      IF (NBLK.EQ.1) IT=ITAPES
C
      DO 230 I=1,NEQB
      D=A(I,1)
      IF (D.EQ.0.) GO TO 230
      M=(I+MIN)/2
      A(I,1)=D+MASS(M)
```

```
  230 CONTINUE
C
      IF (INCORE) RETURN
      WRITE (KTAPE) ((A(I,J),I=1,NEQB),J=1,MBAND)
      IF (NBLK.EQ.NBK) RETURN
      IF (COPL2) GO TO 260
      DO 240 I=1,NRA
      DO 240 J=1,MBAND
      A(I,J)=0.0
  240 CONTINUE
      GO TO 300
C
  260 DO 280 I=1,NEQB
      II=I+NEQB
      DO 280 J=1,MBAND
      A(I,J)=A(II,J)
      A(II,J)=0.0
  280 CONTINUE
C
  300 I=IT
      IT=JT
      JT=I
      REWIND IT
      REWIND JT
      GO TO 140
C
      END
```

```
      SUBROUTINE INTCHG (N1,N2)
      N=N1
      N1=N2
      N2=N
      RETURN
      END
```

```
      SUBROUTINE KLOK(INIT,INTSEC,MAXSEC,IBAIL,SEC,ISEC)
C     KLOK ROUTINE FOR DEPS5 CODE
C      FOR 6400 - CDC
C
        DATA N/1/
        IF(INIT.EQ.0)GO TO 3
        CALL SECOND (XYZ)
       ISEC=XYZ-BEG
      SEC=XYZ-BEG
      IF (SENSE SWITCH 2) 25,5
    5 CONTINUE
        IF(SENSE SWITCH 1)100,200
200      IF(ISEC.GT.MAXSEC.AND.MAXSEC.NE.0)GO TO 100
        IF(ISEC.GT.N*INTSEC.AND.INTSEC.NE.0)GO TO 300
          RETURN
C
C       RESTART FLAG *IBAIL*, GENERATE RESTART TAPE, AND
C         TERMINATE EXECUTION.
C
100       IBAIL=1
          RETURN
C
C       SET RESTART FLAG *IBAIL*, GENERATE RESTART TAPE, AND
C         CONTINUE EXECUTION.
C
  300 CONTINUE
         N=N+1
   25 CONTINUE
           IBAIL=2
        RETURN
C
C       INITIALIZE CORE CLOCK.
C
3       CALL SECOND (BEG)
         INIT=1
C
          RETURN
C
      END
```

```
      SUBROUTINE LOAD (T,P,B,INI,JNJ,HI,HJ,VI,VJ,IK,NSTART,NSTOP,NUMPC,
     1 TT,DELT)
      DIMENSION T(1),P(2,1),B(1),INI(1),JNJ(1),HI(1),HJ(1),VI(1),VJ(1)
C
      IF(NUMPC.EQ.0) GO TO 700
      N=1
  100 TAU=TT-T(N)
      IF(TAU) 500,200,200
  200 IF(TAU.GE.P(1,IK).AND.TAU.LE.P(1,IK+1)) GO TO 300
      IF (TAU.GT.P(1,IK+1)) IK=IK+1
      IF (TAU.LT.P(1,IK))IK=IK-1
      GO TO 200
  300 D=P(1,IK+1)-P(1,IK)
      DH=P(2,IK+1)-P(2,IK)
      IF(TT.EQ.P(1,1)) TAU=-DELT
      DT=TAU-P(1,IK)  +DELT
      F=P(2,IK)+DT*DH/D
  400 I=INI(N)+INI(N)
      II=I-1
      J=JNJ(N)+JNJ(N)
      JJ=J-1
      IF((I.LT.NSTART).OR.(I.GT.NSTOP)) GO TO 425
      B(I-NSTART+1)=B(I-NSTART+1)+F*VI(N)
  425 IF((J.LT.NSTART).OR.(J.GT.NSTOP)) GO TO 450
      B(J-NSTART+1)=B(J-NSTART+1)+F*VJ(N)
  450 IF((II.LT.NSTART).OR.(II.GT.NSTOP)) GO TO 475
      B(II-NSTART+1)=B(II-NSTART+1)+F*HI(N)
  475 IF((JJ.LT. NSTART).OR.(JJ.GT.NSTOP)) GO TO 500
      B(JJ-NSTART+1)=B(JJ-NSTART+1)+F*HJ(N)
  500 N=N+1
      IF(N.GT.NUMPC) GO TO 700
      IF(T(N).EQ.T(N-1)) GO TO 400
      GO TO 100
  700 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE NPLAST(S,E,B,G,ALPHA)
      DIMENSION S(1),E(1),F(4),DS(4)
      DUM=.1667*((S(1)-S(2))**2+(S(2)-S(3))**2+(S(3)-S(1))**2)+S(4)**2
      DUM=SQRT(DUM)
      F(1)=.1667*(2.*S(1)-S(2)-S(3))/DUM-ALPHA
      F(2)=.1667*(2.*S(2)-S(1)-S(3))/DUM-ALPHA
      F(3)=.1667*(2.*S(3)-S(1)-S(2))/DUM-ALPHA
      F(4)=S(4)/DUM
      X=B-.667*G
      FF=F(1)+F(2)+F(3)
      S1=F(1)**2+F(2)**2+F(3)**2+2.*F(4)**2
      D=X*FF**2+2.*G*S1
      EE=E(1)+E(2)+E(3)
      SS=F(1)*E(1)+F(2)*E(2)+F(3)*E(3)+2.*F(4)*E(4)
      DD=X*EE*FF+2.*G*SS
      IF(D.NE.0.) XLAMDA=DD/D
      DS(1)=(X*EE+2.*G*F(1))*XLAMDA
      DS(2)=(X*EE+2.*G*F(2))*XLAMDA
      DS(3)=(X*EE+2.*G*F(3))*XLAMDA
      DS(4)=2.*G*F(4)*XLAMDA
      DO 10 I=1,4
   10 S(I)=S(I)-DS(I)
      RETURN
      END
```

```
      SUBROUTINE ONED (RI,RJ,ZI,ZJ,H,VOL)
      COMMON /LSWARG /LM(8),SS(4,8),XC,YC,S(8,8),C(4,4)
      DIMENSION H(1),ST(4,8)
      DO 410 I=1,8
      DO 405 J=1,4
  405 ST(J,I)=0.
      DO 410 J=1,8
  410 S(I,J)=0.
      XC=.5*(RI+RJ)
      YC=.5*(ZI+ZJ)
      DX=RJ-RI
      DY=ZJ-ZI
      XL=SQRT(DX**2+DY**2)
      VOL=H(4)*XL*XC
      BLK=H(1)
      SHR=H(2)
      CONST=1./(3.*BLK+SHR)
      ENU=.5*CONST*(3.*BLK-2.*SHR)
      E1=9.*CONST*BLK*SHR
      C(1,1)=E1
      C(2,2)=E1
      C(1,2)=ENU*E1
      C(2,1)=C(1,2)
C-----STRAIN DISPLACEMENT RELATION
      ST(1,1)=-DX/XL**2
      ST(1,2)=-DY/XL**2
      ST(1,3)=-ST(1,1)
      ST(1,4)=-ST(1,2)
      ST(2,1)=.5/XC
      ST(2,3)=ST(2,1)
      DO 411 I=1,4
      DO 411 J=1,8
  411 SS(I,J)=0.
      DO 412 I=1,2
      DO 412 J=1,4
      DO 412 K=1,2
  412 SS(I,J)=SS(I,J)+C(I,K)*ST(K,J)
      DO 414 J=1,4
      DO 414 I=1,4
      DO 414 K=1,2
  414 S(I,J)=S(I,J)+ST(K,I)*SS(K,J)*VOL
      RETURN
      END
```

```
      SUBROUTINE OUTPUT(PROP,COEFF,HI,HJ,VI,VJ,T,INI,JNJ,P,R,Z,CODE,B,
     1XO,X1,X2,IX,ED,EPS,SIG,YLDDAT,NTA,NNNO,AJA)
      COMMON HED(12),IFLAG,NUMNP,NUMEL,NUMMAT,NEQB,MBAND,NNN,NT,TT,DELT,
     1 NPRINT,NP,NUMPC,NST,RA,ALFA,BETA,INTSEC,MAXSEC,NTSTOP,MTSTOP,IIK,
     2 M1,M2,M3,MN,ME,LA,IN,IO,LUN1,LUN2,LUN3,LUN4,LUN5,LUN6,LUN7,NTAPE,
     3 MAG,MAGOLD,LUN8,KOM
C
      DIMENSION PROP(7,1),COEFF(60,1),HI(1),HJ(1),VI(1),VJ(1),T(1),
     .INI(1),JNJ(1),P(2,1),R(1),Z(1),CODE(1),B(1),XO(1),X1(1),X2(1),
     .IX(5,1),EPS(10,1),SIG(5,1.,YLDDAT(2,1),ED(1) ,AJA(9)
      REWIND NTAPE
      NNPBLK=(NUMNP+M1-1)/M1
      NELBLK=(NUMEL+M2-1)/M2
      IF (NNNO.NE.0) GO TO 40
      READ (NTAPE)(AJA(I),I=1,9),(HED(I),I=1,12),
     .NUMNP,NUMEL,NUMMAT,NT,NPRINT,NP,NUMPC,NST,ALFA,BETA,DELT,RA
      WRITE (IO,1500)  (AJA(I), I=1,9)
      WRITE (IO,2000)  (HED(I), I=1,12),NUMNP,NUMEL,NUMMAT,NT,NPRINT,
     .  NP,NUMPC,ALFA,BETA,DELT,NST
   40 NT=NTA
      IF (NNNO.NE.0) GO TO 190
C---------
C   READ AND PRINT OF MATERIAL PROPERTIES
C-------
      READ  (NTAPE) ((PROP(I,M),I=1,7),M=1,NUMMAT),((COEFF(I,M),I=1,60)
     1,M=1,NUMMAT)
      WRITE (IO,3500) (AJA(I), I=1,9), (HED(J),J=1,12)
      WRITE (6,1000)
      DO 59 M=1,NUMMAT
      MTYPE=M
      WRITE(6,2700)MTYPE,(PROP(I,MTYPE),I=1,4)
      IF(PROP(6,MTYPE).GT.0.) WRITE(6,2100) (COEFF(I,MTYPE),I=21,50)
      IF(PROP(7,MTYPE).GT.0.) WRITE(6,2200) (COEFF(I,MTYPE),I=51,60)
      INELAS=PROP(5,MTYPE)
      IF(INELAS.LE.0) GO TO 59
      IF(INELAS.EQ.1) WRITE(6,2300)
      IF(INELAS.EQ.2) WRITE(6,2400)
      IF(INELAS.EQ.3) WRITE(6,2500)
      WRITE(6,2600) (COEFF(I,MTYPE),I=1,20)
   59 CONTINUE
      WRITE(6,3500) AJA,HED
      WRITE(6,2001)
      DO 150 I=1,NELBLK
      READ (NTAPE)((IX(J,K),J=1,5),K=1,M2)
      NSTART=M2*(I-1)
      NSTOP=NUMEL-NSTART
      NSTOP=MIN0(M2,NSTOP)
      DO 150 K=1,NSTOP
      NEL=K+NSTART
      WRITE (6,2003)            NEL,(IX(J,K),J=1,5)
  150 CONTINUE
      IF(NUMPC.EQ.0) GO TO 180
      READ  (NTAPE)(HI(K),VI(K),HJ(K),VJ(K),T(K),INI(K),JNJ(K),
     1K=1,NUMPC)
      READ  (NTAPE) ((P(K,M),K=1,2),M=1,NP)
      WRITE(6,3500) AJA,HED
      WRITE(6,2010)
      DO 330 K=1,NUMPC
```

```
      I=INI(K)
      J=JNJ (K)
  330 WRITE (6,2013) I,J,     HI(K),VI(K),HJ(K),VJ(K),T(K)
C----- --
C      READ AND PRINT OF LOAD DATA
C----- ---
      WRITE(6,3500) AJA,HED
      WRITE (6,2007)
      WRITE (6,2005) ((P(K,M),K=1,2),M=1,NP)
  180 DO 181 NBK=1,NELBLK
      READ (NTAPE) ((SIG(I,N),I=1,4),(EPS(I,N),I=1,4),N=1,M2)
  181 CONTINUE
      WRITE(6,3500) AJA,HED
      WRITE(6,2004)
      DO 190 NBK=1,NNPBLK
      READ(NTAPE)(R(I),I=1,MN)
      NSTART=M1*(NBK-1)
      NSTOP=NUMNP-NSTART
      NSTOP=MIN0(M1,NSTOP)
      DO 100 K=1,NSTOP
      NNP=K+NSTART
      WRITE(6,2002) NNP,CODE(K),R(K),Z(K),X0(2*K-1),X0(2*K),X1(2*K-1),
     .X1(2*K),X2(2*K-1),X2(2*K)
  100 CONTINUE
  190 CONTINUE
      TT=P(1,1)
      LL=0
      IF (NNNO.EQ.0) GO TO 195
      XNNNO=NNNO
      TT=TT+XNNNO*DELT
      LL=MOD(NNNO,NPRINT)
  195 DO 500 NNN=1,NT
      LL=LL+1
      TT=TT+DELT
      IF(LL.EQ.NPRINT) GO TO 300
      DO 200 I=1,NNPBLK
      READ (NTAPE)(R(K),Z(K),X0(2*K-1),X0(2*K),X1(2*K-1),X1(2*K),
     .X2(2*K-1),X2(2*K),K=1,M1)
  200 CONTINUE
      DO 250 I=1,NELBLK
      READ (NTAPE) ((SIG(J,N),J=1,4),(EPS(J,N),J=1,4),N=1,M2)
  250 CONTINUE
      GO TO 500
  300 LL=0
      WRITE(6,3500) AJA,HED
      WRITE (6,2006) TT
      DO 350 I=1,NNPBLK
      READ (NTAPE)(R(K),Z(K),X0(2*K-1),X0(2*K),X1(2*K-1),X1(2*K),
     .X2(2*K-1),X2(2*K),K=1,M1)
      NSTART=M1*(I-1)
      NSTOP=NUMNP-NSTART
      NSTOP=MIN0(NSTOP,M1)
      DO 330 K=1,NSTOP
      NNP=K+NSTART
      AA=X0(2*K-1)+R(K)
      BB=X0(2*K)+Z(K)
      WRITE(6,2008) NNP,AA,BB,X0(2*K-1),X0(2*K),X1(2*K-1),X1(2*K),
     .X2(2*K-1),X2(2*K)
```

```
  350 CONTINUE
      WRITE(6,3500) AJA,HED
      WRITE(6,1200)TT
      WRITE(6,1100)
      DO 400 I=1,NELBLK
      NSTART=M2*(I-1)
      READ (NTAPE) ((SIG(J,N),J=1,4),(EPS(J,N),J=1,4),N=1,M2)
      NSTOP=NUMEL-NSTART
      NSTOP=MIN0(M2,NSTOP)
      DO 400 K=1,NSTOP
      NEL=K+NSTART
      WRITE(6,1300)          NEL,(SIG(J,K),J=1,4),(EPS(J,K),J=1,4)
  400 CONTINUE
  500 CONTINUE
      RETURN
 1000 FORMAT(20X,30H TABLE OF MATERIAL PROPERTIES //)
 1100 FORMAT(6H EL.NO,7X,5HSIG-R,7X,5HSIG-Z,7X,5HSIG-T,6X,6HTAU-RZ,
     .7X,5HEPS-R,7X,5HEPS-Z,7X,5HEPS-T,6X,6HEPS-RZ)
 1200 FORMAT(8H TIME T=E10.5)
 1300 FORMAT(I6,8E12.4)
 1500 FORMAT(1H1,20X,9A6/)
 2000 FORMAT (1X,12A6/
     1 30H0 NUMBER OF NODAL POINTS------ I4 /
     2 30H0 NUMBER OF ELEMENTS---------- I4 /
     3 30H0 NUMBER OF DIFF. MATERIALS--- I4 /
     4 30H0 NUMBER OF TIME INCREMENTS--- I4 /
     5 30H0 PRINT INTERVAL-------------- I4 /
     6 30H0 NUMBER OF LOAD POINTS------- I4 /
     7 30H0 NUMBER OF PRESSURE CARDS---- I4 /
     8 30H0 DAMPING COEFFICIENT ALFA---- F10.5 /
     9 30H0 DAMPING COEFFICIENT BETA---- F10.5 /
     . 30H0 TIME INCREMENT-------------- E12.5/
     . 30H0 NUMBER OF VANISHING ELEM---  I5)
 2001 FORMAT (49H ELEMENT NO.       I      J      K      L     MATERIAL  )
 2002 FORMAT(I7,F10.2,6F10.3,2E10.3)
 2003 FORMAT (1I13,4I6, I12)
 2004 FORMAT( 78H NODAL POINT TYPE      R-ORD      Z-ORD      R-DISL      Z-DIS
     .L     R-VEL      Z-VEL      ,20H      R-ACC      Z-ACC)
 2005 FORMAT (2F15.7)
 2006 FORMAT(8H TIME T=E15.5/5H NODE,9X,5HR-ORD,9X,5HZ-ORD,8X,6HR-DISP,
     .8X,6HZ-DISP,9X,5HR-VEL,9X,5HZ-VEL,9X,5HR-ACC,9X,5HZ-ACC)
 2007 FORMAT  (27H          TIME          PRESSURE P)
 2008 FORMAT(I5,8E14.5)
 2010 FORMAT (29H PRESSURE BOUNDARY CONDITIONS/
     1 5X,1HI,5X,1HJ,8X,4HPI/P,8X,4HPJ/P,8X,2HHI,10X,2HVI,10X2HHJ,10X,
     2 2HVJ,11X,1HT)
 2013 FORMAT(2I6,24X,5F12.4)
 2100 FORMAT(13H  BULK COEFF(,10E12.4,/13X,10E12.4/13X,10E12.4,2H )/)
 2200 FORMAT(13H SHEAR COEFF(,10E12.4,2H )/)
 2300 FORMAT(13H OLD PLASTIC /)
 2400 FORMAT(13H NEW PLASTIC /)
 2500 FORMAT(15H VISCO-PLASTIC /)
 2600 FORMAT(13H YIELD COEFF(,10E12.4/10E12.4,2H )/)
 2700 FORMAT(24H MATERIAL NUMBER ------- I5/
     .          24H BULK MODULUS ---------- F15.5,6H (PSI)/
     .          24H SHEAR MODULUS---------- F15.5,6H (PSI)/
     .          24H DENSITY---------------- F15.5/
     .         24H THICKNESS (ONE-D)------ F15.5,5H (IN)/)
```

```
3500 FORMAT(1H1,20X, 9A6// 10X,12A6//)
     END
```

```
      SUBROUTINE PLAST(F,B,G,C)
      DIMENSION F(4),C(4,4)
      F1=F(1)
      F2=F(2)
      F3=F(3)
      F4=F(4)
C
C   LAME S PARAMETER
      X=B-.667*G
      FF=F1 + F2 + F3
      S=F1*F1 + F2*F2 + F3*F3 + 2.*F4*F4
      D=X*FF*FF+2.*G*S
      IF(D.EQ.0.)  D=1.
      A1=X*FF+2.*G*F1
      A2=X*FF+ 2.*G*F2
      A3= X*FF+ 2.*G*F3
C
      C(1,1)= (X+2.*G) -(A1*A1/D)
      C(1,2) = X-(A1*A2/D)
      C(1,3) = X-(A1*A3/D)
      C(1,4) = -2.*G*F4*A1/D
C
      C(2,2) = X+2.*G-(A2*A2/D)
      C(2,3) = X-(A2*A3/D)
      C(2,4) = -2.*G*F4*A2/D
C
      C(3,3) = X+2.*G-(A3*A3/D)
      C(3,4) = -2.*G*F4*A3/D
C
      C(4,4)=G-4.*G*G*F4*F4/D
C
      C(2,1)=C(1,2)
      C(3,1)=C(1,3)
      C(3,2)=C(2,3)
      C(4,1) =C(1,4)
      C(4,2)=C(2,4)
      C(4,3)=C(3,4)
   20 RETURN
      END
```

```
      SUBROUTINE QUAD (R1,R2,R3,R4,Z1,Z2,Z3,Z4,RM,ZM,VOL,D,QK,QS)
C
C     FORMS STIFFNESS MATRIX QK, CENTROIDAL STRESS MATRIX QS
C             FOR A FIVE POINT AXISYMMETRIC IRON S QUAFRILATERAL USING
C     A FOUR POINT INTEGRATION FORMULA.
C     CONSTANT SHEAR STRAIN INTRODUCES INCOMPATIBILITY
      DIMENSION QK(8,8),QS(4,8),D(4,8),TT(4),QC(4,10),SS(4),QQ(10,10)
      DATA SS/ -1.,1.,1.,-1./,TT/-1.,-1.,1.,1./
C
      DO 6 I=1,10
      DO 6 J=1,10
    6 QQ(I,J)=0.
      R12=R1-R2
      R13=R1-R3
      R14=R1-R4
      R23=R2-R3
      R24=R2-R4
      R34=R3-R4
      Z12=Z1-Z2
      Z13=Z1-Z3
      Z14=Z1-Z4
      Z23=Z2-Z3
      Z24=Z2-Z4
      Z34=Z3-Z4
      VOL=R13*Z24-R24*Z13
      RM=(R1+R2+R3+R4)/4.0
      ZM=(Z1+Z2+Z3+Z4)/4.0
      IF (D(1,1).EQ.0) GO TO 888
      Y5=Z24/VOL
      X6=R13/VOL
      X7=R24/VOL
      Y8=Z13/VOL
      X5=-X7
      Y6=-Y8
      Y7=-Y5
      X8=-X6
      DO 30 II=1,4
      S=SS(II)*0.577350269189626
      T=TT(II)*0.577350269189626
      XJ =VOL+S*(R34*Z12-R12*Z34)+T*(R23*Z14-R14*Z23)
      XJAC=XJ/8.0
      SM=1.0-S
      SP=1.0+S
      TM=1.0-T
      TP=1.0+T
      H1=0.25*SM*TM
      H2=0.25*SP*TM
      H3=0.25*SP*TP
      H4=0.25*SM*TP
      R=H1*R1+H2*R2+H3*R3+H4*R4
      G1=H1/R
      G2=H2/R
      G3=H3/R
      G4=H4/R
      GC=SM*SP*TM*TP/R
      X1=(-R24+R34*S+R23*T)/XJ
      X2=( R13-R34*S-R14*T)/XJ
      X3=( R24-R12*S+R14*T)/XJ
```

```
      X4=(-R13+R12*S-R23*T)/XJ
      Y1=( Z24-Z34*S-Z23*T)/XJ
      Y2=(-Z13+Z34*S+Z14*T)/XJ
      Y3=(-Z24+Z12*S-Z14*T)/XJ
      Y4=( Z13-Z12*S+Z23*T)/XJ
      RS=0.25*(-TM*R1+TM*R2+TP*R3-TP*R4)
      ZS=0.25*(-TM*Z1+TM*Z2+TP*Z3-TP*Z4)
      RT=0.25*(-SM*R1-SP*R2+SP*R3+SM*R4)
      ZT=0.25*(-SM*Z1-SP*Z2+SP*Z3+SM*Z4)
      XC=-2.0*(T*SM*SP*RS-S*TM*TP *RT)/XJAC
      YC= 2.0*(T*SM*SP*ZS-S*TM*TP*ZT)/XJAC
      FAC=XJAC*R
C
C     FORM STIFFNESS QK
C
      DO 10 I=1,4
      D1=D(I,1)*FAC
      D2=D(I,2)*FAC
      D3=D(I,3)*FAC
      D4=D(I,4)*FAC
      QC(I,1)=        D1*Y1+D4*X5+D3*G1
      QC(I,3)= D1*Y2 +D4*X6 +D3*G2
      QC(I,5)=        D1*Y3+D4*X7+D3*G3
      QC(I,7)=        D1*Y4+D4*X8+D3*G4
      QC(I,9)=        D1*YC       +D3*GC
      QC(I,2)=        D2*X1+D4*Y5
      QC(I,4)=        D2*X2+D4*Y6
      QC(I,6)=        D2*X3+D4*Y7
      QC(I,8)=        D2*X4+D4*Y8
      QC(I,10)=       D2*XC
   10 CONTINUE
      DO 20 I=1,10
      D1=QC(1,I)
      D2=QC(2,I)
      D3=QC(3,I)
      D4=QC(4,I)
      QQ(1,I)= QQ(1,I) +D1*Y1 +D4*X5 +D3*G1
      QQ(3,I)=QQ(3,I)+D1*Y2+D4*X6+D3*G2
      QQ(5,I)=QQ(5,I)+D1*Y3+D4*X7+D3*G3
      QQ(7,I)=QQ(7,I)+D1*Y4+D4*X8+D3*G4
      QQ(9,I)=QQ(9,I)+D1*YC       +D3*GC
      QQ(2,I)=QQ(2,I)+D2*X1+D4*Y5
      QQ(4,I)=QQ(4,I)+D2*X2+D4*Y6
      QQ(6,I)=QQ(6,I)+D2*X3+D4*Y7
      QQ(8,I)=QQ(8,I)+D2*X4+D4*Y8
      QQ(10,I)=QQ(10,I)+D2*XC
   20 CONTINUE
   30 CONTINUE
C
C     FORM STRESS MATRIX QS AT CENTRIOD (RM,ZM) OF ELEMENT
C
      DO 40 I=1,4
      D1=D(I,1)
      D2=D(I,2)
      D3=D(I,3)/(4.0*RM)
      D4=D(I,4)
      T1=( D1*Z24-D4*R24)/VOL
      T2=(-D1*Z13+D4*R13)/VOL
```

```
      T3=(-D2*R24+D4*Z24)/VOL
      T4=( D2*R13-D4*Z13)/VOL
      QC(I,1)=D3+T1
      QC(I,3)=D3+T2
      QC(I,5)=D3-T1
      QC(I,7)=D3-T2
      QC(I,9)=4.0*D3
      QC(I,2)= T3
      QC(I,4)= T4
      QC(I,6)=-T3
      QC(I,8)=-T4
      QC(I,10)=0.0
   40 CONTINUE
C
C     ELIMINATE CENTRE NODE
C
      DO 50 N=1,2
      L=10-N
      M=L+1
      DO 50 I=1,L
      C=QQ(I,M)/QQ(M,M)
      DO 50 J=1,L
   50 QQ(I,J)=QQ(I,J)-C*QQ(M,J)
C
C     RELOCATE STRESS, STIFFNESS AND LOAD MATRICES
C
  888 CONTINUE
      DO 70 J=1,8
      DO 70 I=1,4
      QK(I,J)=QQ(I,J)
   70 QK(I+4,J)=QQ(I+4,J)
      VOL=VOL*RM/2.
      RETURN
      END
```

```
      SUBROUTINE RESTAT (IBAIL,LCOM,PROP,N11M1,MASS,E,R,NNPBLK,ED,
     1 NELBLK,A,NSTBLK)
C
      REAL MASS
      COMMON HED(12),IFLAG,NUMNP,NUMEL,NUMMAT,NEQB,MBAND,NNN,NT,TT,DELT,
     1 NPRINT,NP,NUMPC,NST,RA,ALFA,BETA,INTSEC,MAXSEC,NTSTOP,MTSTOP,IIK,
     2 M1,M2,M3,MN,ME,LA,IN,IO,LUN1,LUN2,LUN3,LUN4,LUN5,LUN6,LUN7,NTAPE,
     3 MAG,MAGOLD,LUN8,KOM
      DIMENSION PROP(1),MASS(1),E(1),R(1),ED(1),A(1)
C
      NEQ=2*NUMNP
      IF (IBAIL.EQ.3) GO TO 500
C
C     TERMINATION OR STORAGE CYCLE
C
      REWIND MAG
      IF (IFLAG.EQ.1) GO TO 100
      REWIND LUN1
      REWIND LUN2
      REWIND LUN3
  100 WRITE (MAG) LCOM,(HED(I),I=1,LCOM)
      WRITE(MAG) (PROP(I),I=1,N11M1),(E(I),I=1,NEQ),(MASS(I),I=1,NUMNP)
      DO 120 N=1,NSTBLK
      IF (IFLAG.NE.1) READ (LUN1) (A(I),I=1,LA)
      WRITE (MAG) (A(I),I=1,LA)
  120 CONTINUE
      DO 140 N=1,NNPBLK
      IF (IFLAG.NE.1) READ (LUN2) (R(I),I=1,MN)
      WRITE (MAG) (R(I),I=1,MN)
  140 CONTINUE
      DO 160 N=1,NELBLK
      IF (IFLAG.NE.1) READ (LUN3) (ED(I),I=1,ME)
      WRITE (MAG) (ED(I),I=1,ME)
  160 CONTINUE
C
      IF (IBAIL.EQ.1) WRITE (IO,2000) NNN,MAG
      IF (IBAIL.EQ.1) NT=NNN
      IF (IBAIL.EQ.2) WRITE (IO,2001) NNN,MAG
      REWIND MAG
      N=MAGOLD
      MAGOLD=MAG
      MAG=N
      RETURN
C
C     RESTART CYCLE
C
  500 IF (IFLAG.EQ.1) GO TO 520
      REWIND LUN1
      REWIND LUN2
      REWIND LUN3
  520 READ(MAGOLD) (PROP(I),I=1,N11M1),(E(I),I=1,NEQ),
     1 (MASS(I),I=1,NUMNP)
      DO 540 N=1,NSTBLK
      READ (MAGOLD) (A(I),I=1,LA)
      IF (IFLAG.NE.1) WRITE (LUN1) (A(I),I=1,LA)
  540 CONTINUE
      DO 560 N=1,NNPBLK
      READ (MAGOLD) (R(I),I=1,MN)
```

```
      IF (IFLAG.NE.1) WRITE (LUN2) (R(I),I=1,MN)
  560 CONTINUE
      DO 580 N=1,NELBLK
      READ (MASOLD) (ED(I),I=1,ME)
      IF (IFLAG.NE.1) WRITE (LUN3) (ED(I),I=1,ME)
  580 CONTINUE
C
      WRITE (IO,2002) (HED(I),I=1,12)
      N=NNN+1
      WRITE (IO,2003) N
      RETURN
C
 2000 FORMAT (46H0RESTART TAPE GENERATED - EXECUTION TERMINATED,17H WITH
     1 CYCLE NO. =,I10,/33H0THE CURRENT RESTART TAPE IS TAPE,I3)
 2001 FORMAT (45H0RESTART TAPE GENERATED - EXECUTION CONTINUES,17H WITH
     1CYCLE NO. =,I10/33H0THE CURRENT RESTART TAPE IS TAPE,I3)
 2002 FORMAT (1X,12A6)
 2003 FORMAT (44H0RESTART CYCLE COMPLETED-EXECUTION CONTINUES,17H WITH C
     1YCLE NO. =,I10)
C
      END
```

```
      SUBROUTINE SOLVE(PROP,COEFF,HI,HJ,VI,VJ,T,INI,JNJ,P,R,Z,CODE,B,
     1X0,X1,X2,IX,ED,EPS,SIG,YLDDAT,A,E,MASS,EKC,LMC,MBR,BUF,IBAIL,
     2 LCOM,N11M1,IREST,IKLOK)
C
      REAL MASS
      COMMON HED(12),IFLAG,NUMNP,NUMEL,NUMMAT,NEQB,MBAND,NNN,NT,TT,DELT,
     1 NPRINT,NP,NUMPC,NST,RA,ALFA,BETA,INTSEC,MAXSEC,NTSTOP,MTSTOP,IIK,
     2 M1,M2,M3,MN,ME,LA,IN,IO,LUN1,LUN2,LUN3,LUN4,LUN5,LUN6,LUN7,NTAPE,
     3 MAG,MAGOLD,LUN8,KOM
      COMMON /LS4ARG/ LM(8),SS(4,8),XC,YC,S(8,8),C(4,4),DEPS(4)
      COMMON/CORD/RI,RJ,RK,RL,ZI,ZJ,ZK,ZL,COD(4),DISP(8),VEL(8),ACCL(8)
      DIMENSION PROP(7,1),COEFF(60,1),HI(1),HJ(1),VI(1),VJ(1),T(1),
     .INI(1),JNJ(1),P(2,1),R(1),Z(1),CODE(1),B(1),X0(1),X1(1),X2(1),
     .IX(5,1),EPS(10,1),SIG(5,1),YLDDAT(2,1),A(1),E(1),MASS(1),EKC(1),
     .LMC(1),MBR(1),BUF(1),ED(1)
      DIMENSION PCK(4)
      DATA PCK /1HB,8HCYCLE = ,0,0/
C-------
C      INITIALIZATION
C---- --
      IF (IBAIL.EQ.0) REWIND LUN4
      NEQ=NUMNP+NUMNP
      NSTBLK=(NEQ+NEQB-1)/NEQB
      NNPBLK=(NUMNP+M1-1)/M1
      NELBLK=(NUMEL+M2-1)/M2
      IF (IFLAG.EQ.2) NKBLK=(NUMEL+M3-1)/M3
C      ---
C      CONSTANTS FOR THE STEP-BYSTEP SOLUTION
C      ---
      A1=3./DELT
      A2=.75/DELT**2
      A3=A1/2.
      A0 = A2+ A2
      A4=A1/A0
      A5 =2./A0
      A6=DELT/2.
      A7=DELT**2/6.
      A8=A7+A7
C-----FORM STIFFNESS AND MASS MATRIX OF THE SYSTEM
      LK3=64*M3
      LLMB=8*M3
      LA=NEQB*MBAND
C--------
      IF (IBAIL.EQ.3) GO TO 400
      NNN=0
 1000 CONTINUE
      IC=0
      NCPNT=1
      IF (IFLAG.EQ.1) GO TO 52
      REWIND LUN4
      REWIND LUN2
      REWIND LUN3
      REWIND LUN1
      READ (LUN2) (R(I),I=1,MN)
C-----------
C      CLEAR DUMMY AREA
C----------
   52 DO 55 I=1,NUMNP
```

```
      E(2*I-1)=0.
      E(2*I)=0.
      MASS(I)=0.
   55 CONTINUE
      IF (IFLAG.NE.1) GO TO 60
      DO 57 I=1,LA
      A(I)=0.0
   57 CONTINUE
   60 CONTINUE
      DO 380 NBK=1,NELBLK
      IF(IFLAG.NE.1) READ (LUN3) (ED(I),I=1,ME)
      NUMYLD=0
      DO 375 N=1,M2
      NEL=M2*(NBK-1)+N
      IF(NEL.GT.NUMEL) GO TO 376
      DO 199 I=1,4
      J=I+I
      II=IX(I,N)+IX(I,N)
      LM(J)=II
  199 LM(J-1)=II-1
C--------
C     FIND THE ELASTIC CONSTANTS
C---------
      I=IX(1,N)
      J=IX(2,N)
      K=IX(3,N)
      L=IX(4,N)
      MTYPE=IABS(IX(5,N))
      CALL COORD (R,Z,CODE,3,X0,X1,X2,I,J,K,L,NCRNT,NNPBLK,M1,LUN2,MN)
      IF(NNN.NE.0) CALL STRAIN(IX(1,N),EPS(1,N),MTYPE,VOL,PROP(1,MTYPE))
        CALL CONECT(EPS(1,N),SIG(1,N),PROP(1,MTYPE),
     .  COEFF(1,MTYPE),IX(1,N),N,DELT,NUMYLD,YLDDAT,NEL)
C---- ---
C     FORM ELEMENT STIFFNESS MATRICES
      IF(NNN.EQ.NT) GO TO 375
      CALL STIFF(IFLAG,LUN4,M3,NUMEL,NEL,NEQ,VOL,
     .IX(1,N),A,EKC,LKB,LMC,LLMB,PROP(1,MTYPE),MASS,IC,AD)
      IF (NNN.EQ.0) GO TO 375
      DO 370 I=1,4
      DO 370 J=1,8
      JJ=LM(J)
  370 E(JJ)=E(JJ)+SS(I,J)*SIG(I,N)*VOL
  375 CONTINUE
  376 IF(IFLAG.NE.1) WRITE(LUN1) (ED(I),I=1,ME)
      WRITE(NTAPE) ((SIG(I,N),I=1,4),(EPS(I,N),I=1,4),N=1,M2)
      IF(NUMYLD.NE.0) WRITE(IO,2000) TT,((YLDDAT(I,J),I=1,2),J=1,NUMYLD)
 2000 FORMAT(25H INELASTIC ELEMENTS AT T=, E15.6/8(15H    ELE    FACTOR)/
     .  (8(F6.0,F9.6)))
  380 CONTINUE
      IF(IFLAG.NE.1) CALL INTCHG (LUN1,LUN3)
      IF (NNN.EQ.NT) GO TO 390
      IF(IFLAG.NE.1) CALL GSTIFF(LUN4,LUN4,LUN5,LUN1,NEQB,MBAND,NSTBLK,
     .NUMEL,M3,NKBLK,A,NEQB,EKC,EKC,LMC,LMC,MASS)
      IF (NNN.NE.0) GO TO 390
C     INITIAL ACCELERATION
C--------
      IF(IFLAG.EQ.1) GO TO 800
      REWIND LUN2
```

```
      REWIND LUN4
  800 DO 820 NBK=1,NNPBLK
      IF(IFLAG.NE.1) READ (LUN2) (R(I),I=1,MN)
      NSTART=2*(M1*(NBK-1))+1
      NSTOP=2*M1*NBK
      NSTOP=MIN0 (NEQ,NSTOP)
      IK=1
      TT=F(1,1)
      DO 805 I=1,M1
      B(2*M1)=0.
      B(2*M1-1)=0.
  805 CONTINUE
      CALL LOAD(T,P,B,INI,JNJ,HI,HJ,VI,VJ,IK,NSTART,NSTOP,NUMPC,TT,DELT)
      IIK=IK
      DO 810 I=1,M1
      NNP=M1*(NBK-1)+I
      IF(NNP.GT.NUMNP) GO TO 815
      X2(2*I-1)=A0*(B(2*I-1)-E(2*NNP-1))/MASS(NNP)-ALFA*X1(2*I-1)
      X2(2*I)=A0*(B(2*I)-E(2*NNP))/MASS(NNP)-ALFA*X1(2*I)
  810 CONTINUE
  815 IF(IFLAG.NE.1) WRITE(LUN4) (R(I),I=1,MN)
      WRITE(NTAPE)(R(I),I=1,MN)
  820 CONTINUE
      IK=IIK
      IF (IFLAG.NE.1) CALL INTCHG(LUN2,LUN4)
C
  390 IF (IREST.EQ.0) GO TO 405
      CALL KLCK (IKLOK,INTSEC,MAXSEC,IBAIL,SEC,ISEC)
      IF (NNN.NE.MTSTOP) GO TO 395
      MTSTOP=MTSTOP+NTSTOP
      IBAIL=1
  395 IF (IBAIL.EQ.0) GO TO 405
C
  400 CALL RESTAT (IBAIL,LCOM,PROP,N11M1,MASS,E,R,NNPBLK,ED,NELBLK,
     1 A,NSTBLK)
      IBAIL=0
C
  405 NNN=NNN+1
      IF(NNN.GT.NT) RETURN
      TT=TT+DELT
      IF(MOD(NNN,10).EQ.0) CALL DISPLA(PCK,NNN)
      IF(IFLAG.EQ.1) GO TO 410
      REWIND LUN2
  410 DO 450 NBK=1,NNPBLK
      IF(IFLAG.NE.1) READ (LUN2) (R(I),I=1,MN)
      NSTART=2*(M1*(NBK-1))+1
      NSTOP=2*M1*NBK
      NSTOP=MIN0(NSTOP,NEQ)
      DO 420 I=1,M1
      B(2*I-1)=0.
      B(2*I)=0.
  420 CONTINUE
      IK=IIK
      CALL LOAD(T,P,B,INI,JNJ,HI,HJ,VI,VJ,IK,NSTART,NSTOP,NUMPC,TT,DELT)
      DO 430 I=1,M1
      NNP=M1*(NBK-1)+I
      IF(NNP.GT.NUMNP) GO TO 450
      E(2*NNP-1)=B(2*I-1)-E(2*NNP-1)+MASS(NNP)*(A4*X1(2*I-1)+A5*X2(2*I-1
     1))
```

```
      E(2*NNP)=B(2*I)-E(2*NNP)+MASS (NNP)*(A4*X1(2*I)+A5*X2(2*I))
  430 CONTINUE
  450 CONTINUE
  460 CONTINUE
      IIK=IK
      IF(IFLAG.EQ.1) GO TO 465
      REWIND LUN4
      DO 462 I=1,NSTBLK
      NSTART=NEQB*(I-1)+1
      NSTOP=NEQB*I
      WRITE(LUN4) (E(J),J=NSTART,NSTOP)
  462 CONTINUE
  465 CONTINUE
C ---  SAVE MASS VECTOR FOR VANEL
      REWIND LUN8
      WRITE(LUN8) (MASS(I),I=1,NUMNP)
      CALL USOL1(A,BUF,MBR,NEQB,MBAND,NSTBLK,LUN1,LUN5,LUN4,LUN6,LUN7,
     .LUN4)
      IF(IFLAG.EQ.1) GO TO 469
      REWIND LUN4
      DO 467 I=1,NSTBLK
      NSTART=NEQB*(I-1)+1
      NSTOP=NEQB*I
      READ (LUN4) (E(J),J=NSTART,NSTOP)
  467 CONTINUE
  469 CONTINUE
      NDF=0
      IF(IFLAG.EQ.1) GO TO 470
      REWIND LUN2
      REWIND LUN4
  470 DO 480 NBK=1,NNPBLK
      IF(IFLAG.NE.1) READ (LUN2) (R(I),I=1,MN)
      NSTOP=2*M1
      DO 475 I=1,NSTOP
      NDF=NDF+1
      IF(NDF.GT.NEQ) GO TO 476
      ACC=A2*E(NDF)-A3*X1(I)-.5*X2(I)
      B(I)=DELT*X1(I)+A7*(ACC+X2(I)+X2(I))
      X0(I)=X0(I)+B(I)
      X1(I)=X1(I)+A6*(X2(I)+ACC)
      X2(I)=ACC
  475 CONTINUE
  476 IF(IFLAG.NE.1) WRITE (LUN4) (R(I),I=1,MN)
      WRITE(NTAPE)(R(I),Z(I),X0(2*I-1),X0(2*I),X1(2*I-1),X1(2*I),
     .X2(2*I-1),X2(2*I),I=1,M1)
  480 CONTINUE
      IF(IFLAG.NE.1) CALL INTCHG (LUN2,LUN4)
      IF(NST.EQ.0) GO TO 1000
      IF(IFLAG.EQ.1) N1=1
      IF(IFLAG.EQ.2) N1=KOM+1
      N2=N1+NST
      N3=N2+NST
      N4=N3+NST
      N5=N4+NST*2
      N6=N5+NST*2
      N7=N6+NST*2
      N8=N7+NST*2
      CALL VANEL(IX,EO,R,Z,CODE,B,X0,X1,X2,NNPBLK,NELBLK,
     1A(N1),A(N2),A(N3),A(N4),A(N5),A(N6),A(N7),A(N8))
      GO TO 1000
      END
```

```
      SUBROUTINE STIFF (IFLAG,ITAPE,NEB,NUMEL,N,NEQ,VOL,IX,A,EKC,LEK,
     1 LMC,LLM,H,MASS,IC,AO)
C
      COMMON /LS4ARG/ LM(8),SS(4,8),XC,YC,S(8,8),C(4,4),DEPS(4)
      COMMON /CORD/ RI,RJ,RK,RL,ZI,ZJ,ZK,ZL,CODE(4),DISP(8)
      REAL MASS
      DIMENSION IX(1),A(NEQ,1),EKC(1),LMC(1),H(1),MASS(1)
C
      I=IX(1)
      J=IX(2)
      K=IX(3)
      L=IX(4)
      IF (J.NE.K) GO TO 100
      CALL ONED (RI,RJ,ZI,ZJ,H,VOL)
      GO TO 120
  100 CALL QUAD (RI,RJ,RK,RL,ZI,ZJ,ZK,ZL,XC,YC,VOL,C,S,SS)
C
C     MODIFY FOR ZERO DISPLACEMENTS
C
  120 DO 200 I=1,4
      IJ=I+I
      IF (CODE(I).EQ.0.0) GO TO 200
      IF (CODE(I).EQ.1.0) GO TO 160
      DO 140 J=1,8
      S(IJ,J)=0.
  140 S(J,IJ)=0.
  160 IF (CODE(I).EQ.2.0) GO TO 200
      DO 180 J=1,8
      S(IJ-1,J)=0.
  180 S(J,IJ-1)=0.
  200 CONTINUE
C
C     ASSEMBLE GLOBAL MASS VECTOR
C
      CALL GMASS (IX,MASS,AO,H(3),XC,VOL)
C
C     ASSEMBLE GLOBAL STIFFNESS MATRIX IN CORE
C
      IF (IFLAG.EQ.2) GO TO 400
      DO 300 I=1,8
      II=LM(I)
      DO 300 J=1,8
      JJ=LM(J)-II+1
      IF (JJ.LT.1) GO TO 300
      A(II,JJ)=A(II,JJ)+S(I,J)
  300 CONTINUE
      IF (N.LT.NUMEL) RETURN
      DO 320 I=1,NEQ
      D=A(I,1)
      IF (D.EQ.0.) GO TO 320
      J=(I+1)/2
      A(I,1)=D+MASS(J)
  320 CONTINUE
      RETURN
C
C     WRITE ELEMENT DATA ON ITAPE
C
  400 IC=IC+1
```

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```
      II=64*(IC-1)
      JJ=8*(IC-1)
      DO 420 J=1,8
      JJ=JJ+1
      LMC(JJ)=LM(J)
      DO 420 I=1,8
      II=II+1
      EKC(II)=S(I,J)
  420 CONTINUE
      IF ((IC.EQ.NEP).OR.(N.EQ.NUMEL)) GO TO 500
      RETURN
C
  500 WRITE (ITAPE) (EKC(I),I=1,LEK),(LMC(I),I=1,LLM)
      IC=0
      RETURN
C
      END
```

```
      SUBROUTINE STRAIN (IX,EPS,MTYPE,VOL,H)
      DIMENSION IX(5),EPS(10),X(4),H(7),Y(4)
      COMMON / LS4ARG / LM(8),SS(4,8),XC,YC,S(8,8),C(4,4),DEPS(4)
      COMMON/CORD/R(4),Z(4),COD(4),XD(8),VEL(8),ACCL(8)
      DO 200 I=1,4
      DO 200 IK=1,8
  200 SS(I,IK)=0.
C---- --
C     DISPLACEMENT STRAIN TRANSFORMATION MATRIX.
C--------
      I=1
      J=2
      K=3
      L=4
      R13=R(I)-R(K)
      R24=R(J)-R(L)
      Z13=Z(I)-Z(K)
      Z24=Z(J)-Z(L)
      RM=1./(R(I)+R(J)+R(K)+R(L))
      YC=(Z(I)+Z(J)+Z(K)+Z(L))/4.
      IF(IX(2).NE.IX(3)) GO TO 300
C-----SHELL ELEMENT
      XL=R24**2+Z24**2
      SS(1,1)=R13/XL
      SS(1,2)=Z13/XL
      SS(1,3)=-SS(1,1)
      SS(1,4)=-SS(1,2)
      SS(2,1)=RM+RM
      SS(2,3)=SS(2,1)
      VOL=SQRT(XL)*(H(4)*H(4))
      GO TO 400
  300 VOL=R13*Z24-Z13*R24
      Y(1)=Z24/VOL
      Y(2)=-Z13/VOL
      Y(3)=-Y(1)
      Y(4)=-Y(2)
      X(1)=-R24/VOL
      X(2)=R13/VOL
      X(3)=-X(1)
      X(4)=-X(2)
      DO 100 I=1,4
      II=I+I
      JJ=II-1
      SS(1,JJ)=Y(I)
      SS(2,II)=X(I)
      SS(3,JJ)=RM
      SS(4,II)=Y(I)
  100 SS(4,JJ)=X(I)
  400 XC=.25/RM
      VOL=VOL/2.*XC
C-------
C     EVALUATION OF STRAIN.
C--------
      DO 180 I=1,4
      S(I,1)=0.
      DO 180 J=1,8
  180 S(I,1)=S(I,1)+SS(I,J)*XD(J)
      DO 190 I=1,4
```

```
      DEPS(I)=S(I,1)
  100 EPS(I)=EPS(I)+S(I,1)
  320 RETURN
      END
```

```
      SUBROUTINE TSTYLD(IREG,STRESS,II,ALPHA,CEE,YCOF,FACTOR)
      DIMENSION STRESS(4),YCOF(10)
C
C
      S1=STRESS(1)
      S2=STRESS(2)
      S3=STRESS(3)
      S4=STRESS(4)
C
C
      DUM1=.1667*((S1-S2)**2+(S2-S3)**2+(S3-S1)**2)+S4*S4
      DUM2=S1+S2+S3
      DUM1=SQRT(DUM1)
      IF(DUM2.GT.YCOF(5)) GO TO 5
      ALPHA=YCOF(3)
      CEE=YCOF(4)
      GO TO 40
    5 ALPHA=YCOF(1)
      CEE=YCOF(2)
   40 CONTINUE
      IF(II.EQ.2) GO TO 20
      F=DUM1-0.95*(ALPHA*DUM2+CEE)
      IF(F.LE.0.)GO TO 10
C
C   PLASTIC DEFORMATION
C
      IREG=2
      IF(II.EQ.1) RETURN
C      STRESS HAS PROPERLY BEEN COMPUTED BY YLDFUN
   20 DMAX=DUM2
      IF(ALPHA.EQ.0.0)GO TO 50
      DD=-.95*CEE/ALPHA
      IF(DUM2.LT.DD) GO TO 50
      DMAX=DD
      IREG=1
   50 FACTOR=0.
      IF(DUM1.NE.0.)FACTOR=ABS(ALPHA*DMAX+CEE)/DUM1
      IF(FACTOR.EQ.0.) IREG=1
      DO 30 J=1,3
   30 STRESS(J)=(STRESS(J)-DUM2/3.)*FACTOR+DMAX/3.
      STRESS(4)=STRESS(4)*FACTOR
      RETURN
   10 IREG=1
      RETURN
      END
```

```
      SUBROUTINE USOL1 (A,B,MBR,NEQB,MBC,NBK,NO,NT,NS,NS1,NS2,NL)
C
      DIMENSION A(1),B(1),MBR(1)
C
      NK=NEQB*MBC
      NK1=NK+1
      NAB=NK+NEQB
      NC=MBC+1
      NBR=(MBC+NEQB-2)/NEQB
      INC=NEQB-1
      N1=NS1
      N2=NS2
      IF (NBK.EQ.1) GO TO 100
      REWIND NO
      REWIND NT
      REWIND NL
C
C     TRIANGULARIZE MATRIX BLOCK BY BLOCK
C
  100 DO 900 N=1,NBK
      IF (NBK.EQ.1) GO TO 110
      IF (N.GT.1.AND.NBR.EQ.1) GO TO 110
      IF (NBR.EQ.1) GO TO 105
      REWIND N1
      REWIND N2
  105 NI=N1
      IF(N.EQ.1) NI=NO
      IF (NI.NE.NO) GO TO 107
      READ (NI) (A(I),I=1,NK)
      READ (NL) (A(I),I=NK1,NAB)
      GO TO 110
  107 READ (NI) (A(I),I=1,NAB)
C
  110 DO 300 I=1,NEQB
      D=A(I)
      IF (D) 115,300,120
  115 M=NEQB*(N-1)+I
      WRITE (6,2000) M,D
C
  120 II=I
      DO 125 J=2,NC
      II=II+NEQB
      A(II)=A(II)/D
  125 CONTINUE
C
      DO 130 J=I,NK,NEQB
      IF (A(J).NE.0.) MBR(I)=J
  130 CONTINUE
C
      JL=I+1
      IF (JL.GT.NEQB) GO TO 300
      II=I
C
      DO 200 J=JL,NEQB
      II=II+NEQB
      IF (II.GT.NK) GO TO 200
      C=A(II)
      IF (C.EQ.0.) GO TO 200
```

```
      C=C*A(I)
C
      KK=J
      MAX=MBR(I)
      DO 150 JJ=II,MAX,NEQB
      A(KK)=A(KK)-C*A(JJ)
      KK=KK+NEQB
  150 CONTINUE
C
      KK=J+NK
      JJ=I+NK
      A(KK)=A(KK)-C*A(JJ)
  200 CONTINUE
C
  300 CONTINUE
C
      IF (NBK.EQ.1) GO TO 907
      WRITE (NT) (A(I),I=1,NAB),(MBR(I),I=1,NEQB)
C
C     SUBSTITUTE INTO REMAINING EQUATIONS
C
      DO 800 NN=1,NBR
      IF ((N+NN).GT.NBK) GO TO 800
      NI=N1
      IF ((N.EQ.1).OR.(NN.EQ.NBR)) NI=NO
      IF (NI.NE.NO) GO TO 600
      READ (NI) (B(I),I=1,NK)
      READ (NL) (B(I),I=NK1,NAB)
      GO TO 620
  600 READ (NI) (B(I),I=1,NAB)
  620 IL=1+NN*NEQB*NEQB
C
      DO 700 I=1,NEQB
      II=IL
      DO 690 K=1,NEQB
      IF (II.GT.NK) GO TO 680
      C=A(II)
      IF (C.EQ.0.) GO TO 680
      C=C*A(K)
      MAX=MBR(K)
C
      KK=I
      DO 640 JJ=II,MAX,NEQB
      B(KK)=B(KK)-C*A(JJ)
      KK=KK+NEQB
  640 CONTINUE
C
      KK=I+NK
      JJ=K+NK
      B(KK)=B(KK)-C*A(JJ)
  680 II=II-INC
  690 CONTINUE
      IL=IL+NEQB
  700 CONTINUE
C
      IF(NBR.NE.1) GO TO 750
      DO 740 I=1,NAB
      A(I)=B(I)
```

```
  740 CONTINUE
      GO TO 800
  750 WRITE (N2) (B(I),I=1,NAB)
  800 CONTINUE
C
      M=N1
      N1=N2
      N2=M
  900 CONTINUE
C
C     BACK-SUBSTITUTION - RESULTS ON TAPE NS
C
      NRB=NEQB*(NBP+1)
      NUM=NRB-NEQB
      DO 905 I=1,NRB
      B(I)=0.
  905 CONTINUE
      REWIND N1
      REWIND NS
C
  907 DO 986 N=1,NBK
      IF (NBK.EQ.1) GO TO 925
C
      REWIND NT
      NB=NBK-N+1
      DO 910 J=1,NB
      READ (NT) (A(I),I=1,NAB),(MBR(I),I=1,NEQB)
  910 CONTINUE
C
      K=NRB
      DO 915 J=1,NUM
      I=K-NEQB
      B(K)=B(I)
      K=K-1
  915 CONTINUE
C
      I=NK
      K=0
      DO 920 J=1,NEQB
      I=I+1
      K=K+1
      B(K)=A(I)
  920 CONTINUE
C
  925 DO 955 I=1,NEQB
      J=NEQB+1-I
      MAX=MBR(J)
      IF (A(J).NE.0.) GO TO 930
      IF (NBK.NE.1) B(J)=0.0
      IF (NBK.EQ.1) A(NK+J)=0.0
      GO TO 955
  930 KK=J
      JJ=KK+1
      IL=J+NEQB
      IF (NBK.NE.1) C=B(KK)
      IF (NBK.EQ.1) C=A(NK+KK)
      DO 940 II=IL,MAX,NEQB
      IF (NBK.NE.1) C=C-A(II)*B(JJ)
```

```
      IF (NBK.EQ.1) C=C-A(II)*A(NK+JJ)
      JJ=JJ+1
  940 CONTINUE
      IF (NBK.NE.1) B(KK)=C
      IF (NBK.EQ.1) A(NK+KK)=C
  955 CONTINUE
C
      IF (NBK.NE.1) WRITE (N1) (B(I),I=1,NEQB)
  980 CONTINUE
C
      IF (NBK.EQ.1) RETURN
      DO 990 N=1,NBK
      REWIND N1
      NB=NBK-N+1
      DO 985 M=1,NB
      READ (N1) (B(I),I=1,NEQB)
  985 CONTINUE
      WRITE (NS) (B(I),I=1,NEQB)
  990 CONTINUE
C
      RETURN
C
 2000 FORMAT (34H0SET OF EQUATIONS MAY BE SINGULAR./
     1 25H DIAGONAL TERM OF EQUATION,I5,7H EQUALS,1PE11.4)
C
      END
```

```
      SUBROUTINE VANEL (IX,ED,R,Z,CODE,B,X0,X1,X2,NNPBLK,NELBLK,
     1JTAC,ITAC,NELT,VELI,VELJ,ACCI,ACCJ,MASS)
      COMMON HED(12),IFLAG,NUMNP,NUMEL,NUMMAT,NEQB,MBAND,NNN,NT,TT,DELT,
     1NPRINT,NP,NUMPC,NVET,RA,ALFA,BETA,INTSEC,MAXSEC,NTSTOP,MTSTOP,IIK,
     2 M1,M2,M3,MN,ME,LA,IN,IO,LUN1,LUN2,LUN3,LUN4,LUN5,LUN6,LUN7,NTAPE,
     3 MAG,MAGOLD,LUN8,KOM
      COMMON/CORD/RI,RJ,RK,RL,ZI,ZJ,ZK,ZL,COD(4),DISP(8),VEL(8),ACCL(8)
      DIMENSION IX(5,1),ED(1),R(1),Z(1),CODE(1),B(1),X0(1),X1(1),X2(1),
     1JTAC(1),ITAC(1),NELT(1),VELI(1),VELJ(1),ACCI(1),ACCJ(1),MASS(1)
      REAL MASS
      NCRNT=1
      NVEL=0
C --- READ MASS VECTOR
      REWIND LUN8
      READ(LUN8) (MASS(I),I=1,NUMNP)
      IF(IFLAG.EQ.1) GO TO 10
      REWIND LUN2
      REWIND LUN3
      READ (LUN2) (R(I),I=1,MN)
   10 DO 20 I=1,NVET
      NELT(I)=0
      JTAC(I)=0
   20 ITAC(I)=0
      DO 60 NBK=1,NELBLK
      IF(IFLAG.NE.1) READ(LUN3)(ED(II),II=1,ME)
      DO 50 N=1,M2
      NEL=M2*(NBK-1)+N
      IF(NEL.GT.NUMEL) GO TO 55
      IF(IX(5,N).LE.0) GO TO 50
      IF(IX(2,N).NE.IX(3,N)) GO TO 50
      CALL COORD(R,Z,CODE,X0,B,X1,X2,IX(1,N),IX(2,N),IX(3,N),IX(4,N),
     1NCRNT,NNPBLK,M1,LUN2,MN)
      DY=ZJ-ZI+DISP(4)-DISP(2)
      IF((ZJ.GT.ZI).AND.(DY.GT.0.)) GO TO 50
      IF((ZJ.LT.ZI).AND.(DY.LT.0.)) GO TO 50
      NVEL=NVEL+1
      NELT(NVEL)=NEL
      IF(ZJ.LT.ZI) GO TO 40
      JTAC(NVEL)=IX(2,N)
      ITAC(NVEL)=IX(1,N)
      VELI(2*NVEL-1)=VEL(1)
      VELI(2*NVEL)=VEL(2)
      ACCI(2*NVEL-1)=ACCL(1)
      ACCI(2*NVEL)=ACCL(2)
      GO TO 45
   40 JTAC(NVEL)=IX(1,N)
      ITAC(NVEL)=IX(2,N)
      VELI(2*NVEL-1)=VEL(3)
      VELI(2*NVEL)=VEL(4)
      ACCI(2*NVEL-1)=ACCL(3)
      ACCI(2*NVEL)=ACCL(4)
   45 IF(NVEL.GE.NVET) GO TO 65
   50 CONTINUE
   55 CONTINUE
   60 CONTINUE
   65 CONTINUE
      IF(NVEL.EQ.0) RETURN
      NVET=NVET-NVEL
```

```
      IF(IFLAG.EQ.1) GO TO 100
      REWIND LUN1
      REWIND LUN2
      REWIND LUN3
      REWIND LUN4
  100 DO 200 NBK=1,NELBLK
      IF(IFLAG.NE.1) READ(LUN3) (ED(I),I=1,ME)
      DO 150 N=1,M2
      NEL=M2*(NBK-1)+N
      IF(NEL.GT.NUMEL) GO TO 160
      DO 110 K=1,NVEL
      IF(NEL.EQ.NELT(K)) IX(5,N)=-IX(5,N)
      IF(IX(2,N).EQ.IX(3,N)) GO TO 110
      DO 105 I=1,4
      IF(IX(I,N).EQ.ITAC(K)) IX(I,N)=JTAC(K)
  105 CONTINUE
  110 CONTINUE
  150 CONTINUE
  160 IF(IFLAG.NE.1) WRITE(LUN1)(ED(I),I=1,ME)
  200 CONTINUE
      WRITE(6,2000) TT,(NELT(K),K=1,NVEL)
      WRITE(6,1000) TT,(ITAC(K),K=1,NVEL)
      IF(IFLAG.NE.1) CALL INTCHG (LUN1,LUN3)
      DO 400 NBK=1,NNPBLK
      IF(IFLAG.NE.1) READ (LUN2) (R(I),I=1,MN)
      DO 300 N=1,M1
      NPP=M1*(NBK-1)+N
      IF(NPP.GT.NUMNP) GO TO 350
      DO 260 K=1,NVEL
      IF(NPP.NE.ITAC(K)) GO TO 250
      X0(2*N)=-Z(N)
      X0(2*N-1)=0.
      X1(2*N-1)=0.
      X2(2*N-1)=0.
      X1(2*N)=0.
      X2(2*N)=0.
      CODE(N)=3.0
  250 CONTINUE
      IF(NPP.NE.JTAC(K)) GO TO 260
      I=ITAC(K)
      J=JTAC(K)
      R1=MASS(I)/(MASS(I)+MASS(J))
      R2=MASS(J)/(MASS(I)+MASS(J))
      X2(2*N-1)=R2*X2(2*N-1)+R1*ACCI(2*K-1)
      X1(2*N-1)=R2*X1(2*N-1)+R1*VELI(2*K-1)
      X1(2*N)   =R2*X1(2*N)   +R1*VELI(2*K)
      X2(2*N)   =R2*X2(2*N)   +R1*ACCI(2*K)
  260 CONTINUE
  300 CONTINUE
  350 CONTINUE
  360 IF(IFLAG.NE.1) WRITE(LUN4) (R(I),I=1,MN)
  400 CONTINUE
      IF(IFLAG.NE.1) CALL INTCHG(LUN2,LUN4)
      RETURN
 1000 FORMAT(26H NODAL POINTS REMOVED A T=,E10.4,5H(SEC)/(24I5))
 2000 FORMAT(24H ELEMENTS REMOVED AT,T=,E10.4,5H(SEC)/(24I5))
      END
```

```
      SUBROUTINE VPLAST(STRESS,A,C,GAMMA,G,FACTOR,DELT)
      DIMENSION STRESS(1),S(4),DSTRVP(4)
      XJ1=STRESS(1)+STRESS(2)+STRESS(3)
      DO 10 I=1,3
   10 S(I)=STRESS(I)-XJ1/3.
      S(4)=STRESS(4)
      XJP2=((S(1)-S(2))**2+(S(2)-S(3))**2+(S(3)-S(1))**2)/6.+S(4)**2
      XJP2=SQRT(XJP2)
      FACTOR=XJP2/(A*XJ1+C)-1.
      IF(FACTOR.LE.0.) RETURN
      DO 20 I=1,4
      DSTRVP(I)=GAMMA*G*FACTOR*S(I)*2.*DELT/XJP2
   20 STRESS(I)=STRESS(I)-DSTRVP(I)
      RETURN
      END
```

```
      SUBROUTINE YLDFUN(S,COEFF,B,G,ALPHA,CEE,IREG)
      DIMENSION S(4),COEFF(4,4)
      DIMENSION F(4)
      DUM=.1667*((S(1)-S(2))**2+(S(2)-S(3))**2+(S(3)-S(1))**2)+S(4)*S(4)
      DUM=SQRT(ABS(DUM))
      IF(DUM.EQ.0.)  DUM=1.
      F(1)=(.1667*(2.*S(1)-S(2)-S(3))/DUM)-ALPHA
      F(2)=(.1667*(2.*S(2)-S(1)-S(3))/DUM)-ALPHA
      F(3)=(.1667*(2.*S(3)-S(1)-S(2))/DUM)-ALPHA
      F(4)=   S(4)/DUM
C
      CALL PLAST(F(1),B,G,COEFF(1,1))
C
      RETURN
      END
```